Is ICT Still Polarising Labour Demand after the Crisis?

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Abstract

The impact of ICT capital accumulation and digitisation on labour demand and wage structures has changed in recent years, according to some of the literature on the subject. We analyse the impact of ICT capital accumulation based on recent data differentiating between the period before and after the global financial crisis. Methodologically, we draw on Michaels, Natraj and van Reenen (2014) and are able to corroborate their findings for the period 1980-2004, whereas we find distinctly different patterns since 2011. Results suggest a negative relationship between changes in ICT intensity and the wage share for high-skilled workers, whereas medium-skilled workers were the main beneficiaries in sectors that experienced a more intensive digitisation process. These results are chiefly driven by the dynamics in the Central and Eastern European economies and the service industries. The effect of digitisation on low-skilled workers does not reveal any robust significant impact.

Keywords: ICT capital, skill polarisation, wage patterns

JEL classification: J31, O33

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1. Introduction

Since the 1980s, the composition of the labour force and the remuneration of skills in advanced economies have undergone structural changes. One of the most important trends that has been observed has been the decline in demand for high school graduates (medium-skilled) relative to college graduates (high-skilled) – see, for example, Goos et al., 2019. In several labour markets, the demand for medium-skilled workers has even declined relative to low-skilled workers, leading to a so-called polarisation of the labour market, particularly in the US and the UK, but to a lesser extent in the rest of Europe (Goos and Manning, 2007; Goos, Manning and Salomons, 2009; Acemoglu and Autor, 2011).

Research suggests that technological change and also international trade and off-shoring have been the main driving forces behind this pattern (Goos, Manning and Salomons, 2014; Autor, Dorn and Hanson, 2015; Acemoglu et al., 2016). In particular, the diffusion of digital technologies since the 1980s has accelerated this process (Autor, Levy and Murnane, 2003). In the 1980s and 1990s, it was mainly high-skilled workers who possessed computer skills, as education was too slow to adapt to the take-up of the new technology (Goldin and Katz, 2009). Thus, the demand for high-skilled workers increased particularly in the early phase of the adoption of digital technologies, raising skill premiums (Krueger, 1993). After the initial stage of the diffusion of digital technologies, these have been adopted across all sectors, and education systems have provided students with the demanded digital skills. As a consequence, several studies, notably for the US, have documented that the increase in wage premium for high-skilled workers and cognitive skill has slowed down or even stalled since the 2000s (Valletta, 2019; Acemoglu and Autor 2011).

The objective of this research is, first, to test whether the relationship between information and communication technology (ICT) and labour demand has altered since the 2000s compared with the earlier phase of the diffusion of digital technologies (1980-2000). Second, we broaden the geographical scope and analyse whether the observed trend in the US can also be seen across a broader set of developed economies. The basis for our analysis is a study conducted by Michaels, Natraj and van Reenen (2014) (MNvR) for 11 OECD countries between 1980 and 2004. MNvR have found that a rise in a sector's ICT intensity, proxied by ICT capital compensation, has been associated with a rising wage share of high-skilled workers at the cost of medium-skilled workers. We extend this analysis to the period 2011-2016, based on the recent release of the EU KLEMS data (see Adarov and Stehrer, 2019; Stehrer et al., 2019).

The empirical analysis by MNvR builds on the so-called routinisation hypothesis proposed by Autor, Levy and Murnane (2003). The theory suggests that ICT capital can substitute labour more easily in so-called routine tasks that follow a repetitive pattern and hence can be carried out by an algorithm or a programmable machine. Capital, in contrast, complements labour in non-routine cognitive tasks that cannot easily be expressed as a set of programmable rules. Research has shown that routine tasks are mainly concentrated among occupations located in the middle of the wage distribution; non-routine cognitive tasks, in contrast, are mainly carried out by high-skilled workers (Europe: Goos, Manning and Salomons, 2009; UK: Goos and Manning, 2007; US: Acemoglu and Autor, 2011). The falling price of

ICT, which accelerated its take-off, has led to an increase in demand for workers in well-paid occupations, but has lowered demand for middle-income jobs such as clerks and craft workers (Autor, Levy and Murnane, 2003). In some economies, the demand for middle-income jobs has even deteriorated relative to low-income jobs, which are often characterised by non-routine manual tasks and cannot be easily substituted with capital. While employment in medium-paid occupations has declined and employment in high-paid occupations has increased in almost all developed economies, low-income jobs have seen gains mainly in the US (Autor, Levy and Murnane, 2003) and the UK (Goos and Manning, 2007), but to a lesser extent in the EU (Goos, Manning and Salomons, 2009).

The described structural shifts in labour demand have mainly been measured as a change in hours worked in specific occupations. Acemoglu and Autor (2011) and Oesch and Rodríguez Menés (2011), for example, rank occupations based on their income in a base year and measure the changes in employment within these occupations. Based on 1980 US data, MNvR link occupations to the skill level of the workforce (proxied by education). The authors find that occupations that were characterised by non-routine cognitive tasks were mainly occupied by high-skilled workers. Medium-skilled workers were most likely to conduct routine manual and routine cognitive tasks. Finally, low-skilled workers are the largest group within non-routine manual and routine cognitive occupations. The routinisation hypothesis therefore predicts that ICT increases demand for high-skilled workers, but reduces demand for medium-skilled workers, and gives no clear prediction for low-skilled workers (MNvR, 2014).

Recent studies, however, show that the wage premium for college graduates has been growing at a slower rate – or even stalled around the turn of the millennium in the US (Valletta, 2019; Acemoglu and Autor 2011). Similarly, Castex and Kogan Dechter (2014) have found that the return to non-cognitive skills has increased since the 1990s. Beaudry, Green and Sand (2016) call this trend the 'reversal in the demand for skill'. Edin et al. (2017) summarise that several explanations have been put forward to explain this trend. Deming (2017) claims that the demand for skill is shifting and highlights that wage growth has been stronger in occupations that require social skills. Beaudry, Green and Sand (2016) have argued that the early investment stage saw high and growing demand for cognitive tasks to facilitate the adoption of digital technologies. As digital skills and the use of ICT have become ubiquitous, the technology has reached maturity, eventually reducing the premium for digital skills. Hershbein and Kahn (2017) corroborate this argument and show that occupations that were traditionally characterised by routine tasks have experienced upskilling, particularly during the global financial crisis (GFC). This implies that workers with cognitive skills have been increasingly drawn into less well-paid occupations. A complementary argument by Brynjolfsson and McAfee (2014) suggests that the progress in computing technology allows capital to compete more effectively with non-routine cognitive tasks, thereby lowering demand for high-skilled workers.

In this study, we build on the research by MNvR, and corroborate their main finding for the period 1980-2004: a sector's increase in the adoption of ICT was accompanied by a reduction in the demand for medium-skilled workers but increased the demand for high-skilled workers. Furthermore, changes in the ICT intensity did not affect the demand for low-skilled workers. Our findings indicate, however, that this result is sensitive to the industries under consideration. We find that an increased ICT intensity was associated with higher (lower) demand for high- (medium-) skilled workers only in tradable industries. Focusing on the more recent years, based on the EU KLEMS data released in 2019, we find that a larger increase in ICT intensity was generally not associated with an increasing (decreasing) demand for high- (medium-) skilled workers during the period 2011-2016. In addition, contrary to the findings for the period 1980-2004 for Western European economies, we find that a higher ICT intensity was associated with an increase (decrease) in medium- (high-) skilled workers for Eastern European economies in 2011-2016. The driving force behind this pattern appeared to be the service sector. This result needs to be interpreted carefully, however, owing to the sensitivity to sample selection.

In the next section, we show selected descriptive statistics comparing the periods 1980-2004 and 2011-2016. In Section 3, we present our empirical results and we set out our conclusions in Section 4.

2. Data and descriptive evidence

2.1. DATA

The data for this research are the various releases of the EU KLEMS data, providing information on ICT capital stocks, value added, and employment in terms of hours worked and persons employed over a longer period, and a larger set of countries including the EU27 member states together with Japan, the UK and the US (for details, see Timmer et al., 2010; Stehrer et al., 2019).[1] Importantly, attempts have been made to split the information on labour inputs and corresponding hourly incomes into various dimensions such as age, gender and educational attainment. For this study, the latter category is investigated. As mentioned above, first the results from MNvR are reproduced to the extent possible (data for some countries are not available to us), and secondly the analysis is extended to a larger set of countries (including the Central and Eastern European economies) and for more recent years. The first part spans a longer time period, back to the 1980s, but covers only a few economies, whereas the second part includes a larger set of countries with data starting only in 2008. For a number of countries, data on wages by the various employment categories are not available before this date (for details, see Stehrer et al., 2019). A further important difference concerns the data on capital stocks. In the previous EU KLEMS release, these have been calculated from time series on gross fixed capital formation, whereas in the later releases data on capital stocks have been provided by national statistics institutes via Eurobase. These differences should be kept in mind when interpreting the results.

2.2. DESCRIPTIVE RESULTS

MNvR develop an empirical model where the wage share of the respective skill groups is a function of relative wages and capital compensation. The wage share $SHARE^s = \frac{W^s N^S}{W^H N^H + W^M N^M + W^L N^L}$ of the high, medium and low skill groups $s = \{H, M, L\}$ is defined as the labour income (the respective wage rate W^s multiplied by the number of supplied hours N^s) by the skill group as a share of income earned by all three skill groups. Capital compensation is divided into ICT capital compensation and non-ICT capital compensation. Subsequently, we refer to ICT intensity as ICT capital compensation as a share of gross value added (GVA); non-ICT intensity is defined analogously.

Before turning to developments in the wage share, we highlight the patterns of skill upgrading across countries between 1980 and 2004. The share of hours provided by high-skilled workers has been growing across all countries at least since the 1980s.[2] Across all regions, the share of high-skilled workers grew at a similar pace between 1980 and 2004, by an annual rate of around half a percentage point. The rate was highest in the UK and lowest in Western Europe. Between 1980 and 2004, the share

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1 Adarov and Stehrer (2019) provide evidence on the productivity slowdown and the role of ICT and intangible capital using these data.

2 Note that the levels of wage shares by skill groups are not strictly comparable across countries, owing to different education systems. Moreover, wage shares by skill group are not strictly comparable across the two periods of interest 1980-2004 and 2011-2016, owing to changes in the ISCED classification. Nonetheless, these data provide important information on levels and trends.

of medium-skilled workers grew at a similar, although slightly higher, rate than for college graduates. The exception is the US, where the share of medium-skilled workers declined by 0.08 percentage points annually. Furthermore, the supply of low-skilled hours declined across all economies. This share declined most sharply in Japan and the UK, at an annual rate of around 1.2 pp; in the US, the decline was much smaller (0.4 pp).

Although the share of hours provided by medium-skilled workers grew more strongly than that of high-skilled workers, the wage share of college graduates saw relatively stronger. In the case of the US, the wage share decreased by more than the drop in the hours share. Interestingly, while the decline in the wage share of low-skilled workers was substantial, it was similar in magnitude to the decline in hours worked. This pattern supports the finding that relative wages of middle-skilled workers declined, leading to wage polarisation in the US.

Table 1 / Descriptive statistics: Hours shares, by skill group

	HS 1980	MS 1980	LS 1980	HS 80-04	MS 80-04	LS 80-04	HS 2011	MS 2011	LS 2011	HS 11-16	MS 11-16	LS 11-16
Eastern Europe	.	.	.	.	.	.	28.11	62.24	9.65	0.31	-0.24	-0.07
JP	12.90	51.57	35.52	0.54	0.61	-1.15	35.06	61.62	3.32	0.33	-0.15	-0.18
UK	5.10	53.81	41.09	0.57	0.63	-1.20	28.44	39.63	31.93	0.48	-0.10	-0.38
US	20.17	60.69	19.14	0.47	-0.08	-0.39	32.53	58.13	9.33	0.51	-0.37	-0.13
Western Europe	.	.	.	.	.	.	32.46	46.38	21.16	0.50	-0.21	-0.29
Western Europe (MNvR)	7.06	49.80	43.14	0.42	0.53	-0.94	30.06	44.98	24.96	0.48	-0.14	-0.34

Note: Country groups represent unweighted means: Western Europe (MNvR): AT, DK, ES, FI, IT, JP, NL, UK, US; Western Europe: WE (MNvR) + BE, DE, FR, LU, SE; Eastern Europe: CZ, EE, LT, LV, RO, SI, SK; Figures for 1980-2004 and 2011-2016 are annual averages.
Sources: EU KLEMS; own calculations.

Table 2 / Descriptive statistics: Wage shares, by skill group

	HS 1980	MS 1980	LS 1980	HS 80-04	MS 80-04	LS 80-04	HS 2011	MS 2011	LS 2011	HS 11-16	MS 11-16	LS 11-16
Eastern Europe	.	.	.	.	.	.	41.80	53.19	5.01	-0.09	0.15	-0.06
JP	20.42	50.21	29.36	0.67	0.30	-0.97	50.59	46.67	2.73	0.32	-0.17	-0.16
UK	9.21	53.40	37.39	0.77	0.47	-1.24	40.78	35.78	23.44	0.45	-0.15	-0.29
US	27.77	57.02	15.22	0.83	-0.40	-0.42	54.31	33.72	11.97	0.01	-0.02	0.02
Western Europe	.	.	.	.	.	.	41.64	42.88	15.48	0.30	0.02	-0.32
Western Europe (MNvR)	12.38	52.25	35.37	0.52	0.34	-0.86	38.40	42.94	18.66	0.25	0.10	-0.35

Note: Country groups represent unweighted means: Western Europe (MNvR): AT, DK, ES, FI, IT, JP, NL, UK, US; Western Europe: WE (MNvR) + BE, DE, FR, LU, SE; Eastern Europe: CZ, EE, LT, LV, RO, SI, SK; Figures for 1980-2004 and 2011-2016 are annual averages.
Sources: EU KLEMS; own calculations.

The skill upgrading continued after the GFC. The relative labour supply of high-skilled workers increased annually by around half a percentage point in the UK, the US and Western Europe. In Eastern Europe and Japan, the increase was only around one-third of a percentage point annually between 2011 and 2016. The relative supply of both medium- and low-skilled labour declined in the post-GFC era although at a slower annual rate than in 1980-2004. In Japan, the UK and the US, the wage share follows a similar pattern to the hours share. In contrast, in Eastern Europe, the wage share for high-skilled workers declined by 0.09 pp despite growth of 0.3 pp in the share of hours worked. This contrasts with the experience of medium-skilled workers, whose wage share increased despite a decline in relative supply. In Western Europe, the wage share of medium-skilled workers remained almost unchanged despite an annual relative decline in hours supplied of 0.2 pp. The changes in the wage shares in Western Europe stem from the shift from low-skilled workers to college graduates: while the share of college graduates increased annually by around 0.3 pp, it decreased by the same amount for low-skilled workers. To summarise, in all jurisdictions a relative increase in the labour supplied by college graduates has been observed and the share for medium- and low-skilled workers has been falling. While the wage shares for low-skilled workers decreased in tandem (with the exception of the US) with the supply, shifts between medium and high-skilled workers between 2011 and 2016 are rather heterogenous across economies.

Turning to the developments in capital compensation, Table 3 shows that ICT capital compensation as a share of gross value added (GVA) amounted to around 2% in all economies in 1980. Until 2004, the ICT intensity increased to 5.5% in the US and 4% in Western Europe. It increased most strongly in the UK and the US, at an annual rate of 0.14 pp and 0.13 pp respectively, and only at around 0.05 pp in Western Europe.

Table 3 / Change in ICT intensity (left panel: 1980-2004, right panel: 2011-2016)

	ICT 1980	Non-ICT 1980	ICT 80-04	Non-ICT 80-04	ICT 2011	Non-ICT 2011	ICT 11-16	Non-ICT 11-16
Eastern Europe	.	.	.	.	1.88	42.39	-0.07	-0.49
JP	1.81	31.42	0.11	0.35	3.82	23.45	-0.22	-1.02
UK	1.90	26.23	0.14	-0.15	1.85	31.86	-0.04	0.24
US	2.41	31.07	0.13	-0.03	2.37	41.42	-0.01	-0.06
Western Europe	.	.	.	.	1.97	34.00	0.05	0.06
Western Europe (MNvR)	2.05	27.28	0.08	0.19	1.82	32.31	0.04	0.17

Note: Country groups represent unweighted means: Western Europe (MNvR): AT, DK, ES, FI, IT, JP, NL, UK, US; Western Europe: WE (MNvR) + BE, DE, FR, LU, SE; Eastern Europe: CZ, EE, LT, LV, RO, SI, SK
Sources: EU KLEMS; own calculations.

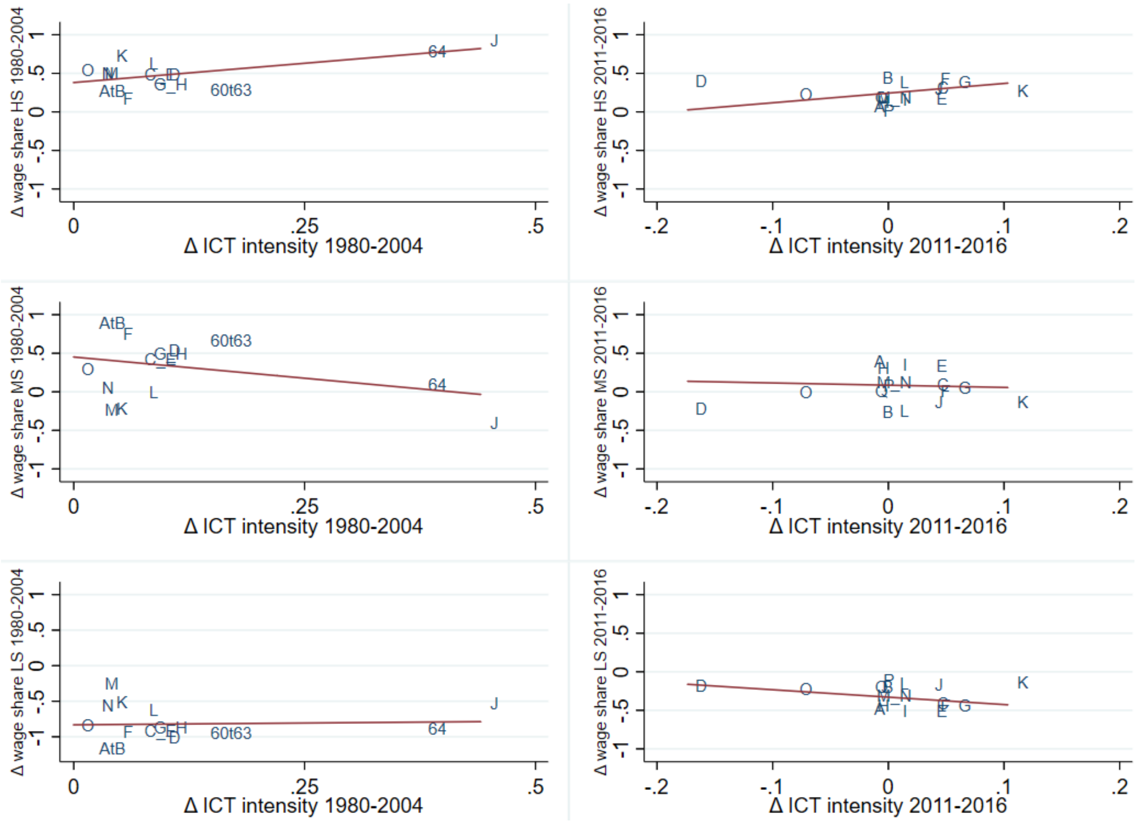
The ICT intensity variable from the EU KLEMS release in 2009 cannot be directly compared to the release in 2019, owing to different estimation methods (see above). For overlapping periods, where data for ICT intensity is available for both periods, ICT intensity is only around half in the data from the 2019 release compared with the 2009 release. As indicated in Table 3, the ICT intensity in 2011 is about the same magnitude as in 1980 if data from the two series are compared directly. Thus, the methods used to estimate ICT intensity are likely to have strong implications for the estimation results presented in Section 3. Between 2011 and 2016 ICT capital compensation declined across all jurisdictions except for continental Western Europe, where it increased by 0.05 pp annually. The largest drops were observed in Japan (-0.22 pp) and Eastern Europe (-0.07 pp).

Non-ICT capital compensation ranged between 26% and 31% of GVA in 1980 – compared with ICT capital compensation of around 2%. The evolution of non-ICT intensity follows different trends across economies. While it increased in Japan and Western Europe, it decreased in the UK and the US between 1980 and 2004. In 2011 non-ICT intensity varied strongly across the economies. While it amounted to 23% in Japan and 34% in Western Europe, the share was 41% in the US. Similarly, no common trends across jurisdictions can be observed between 2011 and 2016.

The variation in ICT intensity across sectors was already pronounced in 1980. Based on averages across all available countries, it amounted to 0.3% in agriculture and construction, and it was as high as 4% in social services, 6% in financial intermediation and 14% in post and telecommunications. Figure 1 shows correlation between the changes in wage shares and changes in ICT intensity for the different skill groups. Between 1980 and 2004 the development of two sectors stands out. Financial intermediation and post and telecommunications, which already had the highest ICT intensity in 1980, experienced annual increases of around 0.4 pp. Transport and storage is the sector with the third-highest rate (0.14 pp), while the remaining sectors experienced growth rates of less than 0.1 pp.

In 2011, for which data are available only in NACE 2 classification, ICT capital compensation is strongly concentrated in the information and communication and the financial and insurance sectors, where it amounted to 13% and 9% respectively. In the remaining sectors, the level was less than 4%. Sectoral changes between 2011 and 2016 were mixed. The energy sector and public administration and defence experienced the largest declines in ICT intensity, of 0.15 pp and 0.08 pp annually. Increases were more modest and did not exceed 0.04 pp in any of the sectors.

Figure 1 / Sector-level correlation between ICT intensity and wage share, by skill group

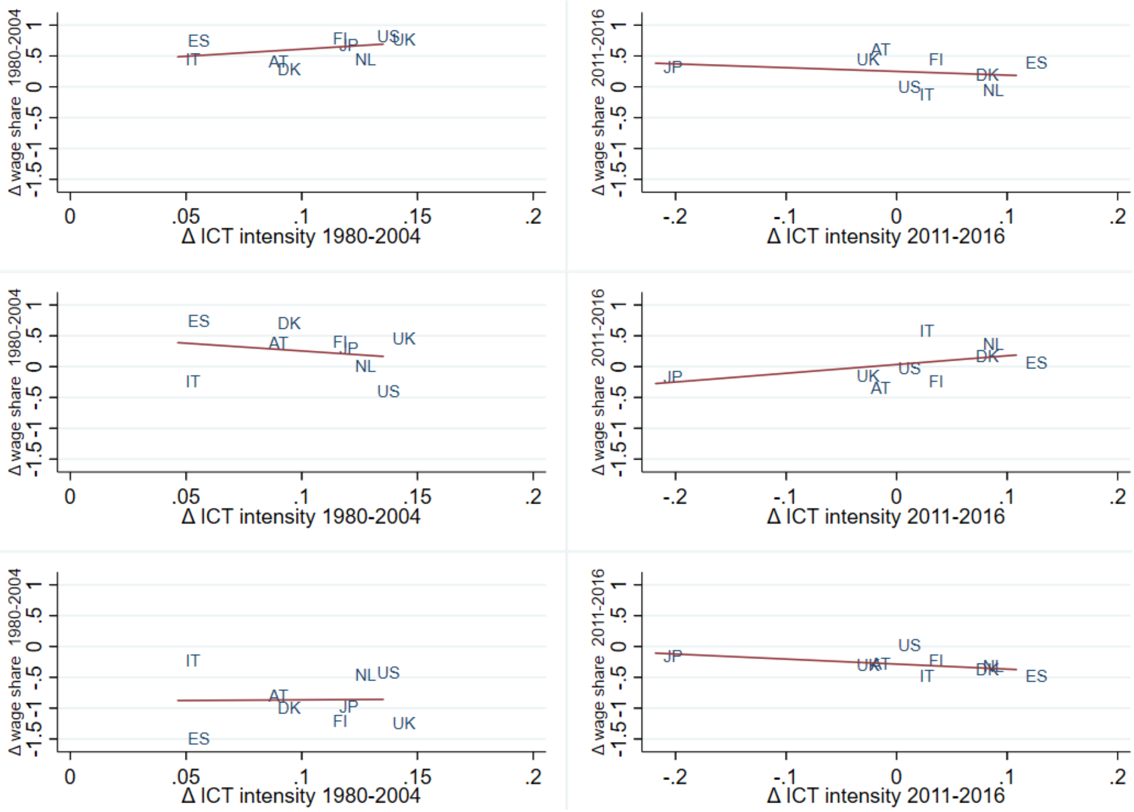


Note: Data points are annual growth rates and represent unweighted sample means; sample: AT, DK, ES, FI, IT, JP, NL, UK, US; sub-sectors are not shown, owing to different availability across countries; sector classification: NACE 1 (1980-2004), NACE 2 (2011-2016); HS = high skill, MS = medium skill, LS = low skill.
Sources: EU KLEMS; own calculations.

Figure 1 shows the correlation between ICT intensity and wage shares at sectoral level for the respective skill groups between 1980 and 2004 (left panel) and 2011 and 2016 (right panel).[3] As already shown by MNvR, ICT intensity is positively correlated with changes in high-skilled wage shares during both periods. Furthermore, it is negatively correlated with medium-skilled wage shares and appears neutral for low-skilled wage shares between 1980 and 2004. However, the correlation charts indicate a change in the correlation for the period 2011-2016. There appears to be a neutral relationship between ICT intensity and the wage share for the medium-skilled, and a negative relationship for low-skilled workers. The correlation coefficient for college graduates is positive.

This relationship also holds when plotting observations at the national level for the period 1980-2004 – see Figure 2. For the period 2011-2016, however, the correlation pattern is not in line with the theoretical predictions. Figures A1 and A2 in the Appendix, which show the correlation for Western European and Eastern European countries separately, also reveal that the sign of the correlation coefficient depends on the geographic focus.

Figure 2 / Country-level correlation between ICT intensity and wage share, by skill group



Note: Changes are expressed in annual growth rates of the total economy.
Sources: EU KLEMS; own calculations.

3 The sample is the same across panels to avoid influence arising from additional observations from another set of countries.

3. Econometric approach and results

3.1. METHODOLOGICAL APPROACH

In the model developed by MNvR, output is produced by three skill groups (H, M, L) and ICT capital. It is assumed that ICT capital complements high-skilled workers, substitutes medium-skilled workers and does not augment the labour input of low-skilled workers. The model predicts that an increase in ICT intensity leads to an increase in the high-skill wage share but reduces the medium-skill share, while the change in the low-skill share is ambiguous.

In order to test their theoretical predictions, MNvR estimate the following empirical model:

$$\Delta SHARE_{ijt}^{s} = c_j^s + \beta_1^s \Delta \left(\frac{C}{Q}\right)_{ijt} + \beta_2^s \Delta \left(\frac{K}{Q}\right)_{ijt} + \Delta ln\, Q_{ijt} + u_{ijt}^s \quad (1)$$

In their analysis, MNvR estimate long differences in the wage share in sector i, country j for the time period t. The variables of interest are ICT intensity, measured as capital compensation C as a share of GVA Q, and changes in non-ICT intensity, measured as non-ICT capital compensation K as a share of GVA. u_{ijt}^s is the error term.

In their main specification, the authors estimate the difference between 1980 and 2004 for a sample of 11 countries.[4] The number of sectors varies across jurisdictions owing to the provision of different levels of aggregation by the national statistical agencies.[5]

In our analysis, we follow the approach suggested by MNvR and estimate the model (1). The objective is to reproduce the results for 1980-2004 and extend the analysis to the post-GFC period 2011-2016. Note that, owing to breaks in the data – particularly relating to changes in the NACE classification, but also in the estimation of capital compensation – it is not possible directly to compare the estimates for the period 1980-2004 to the period 2011-2016.

As MNvR highlight, the empirical strategy does not allow for causal interpretation, but should be interpreted as conditional correlations.

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4 Austria, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Spain, UK, US.

5 Owing to the oil price shocks in the 1980s, MNvR exclude the sectors mining and quarrying, energy, and manufacturing of refined oil products.

3.2. ECONOMETRIC RESULTS

As a first step, we reproduce the results presented in MNvR. It needs to be noted, however, that there are some minor differences between our data and the data used in MNvR. First, we do not have access to data for Germany and France. Second, the descriptive statistics reveal sizeable differences for the Netherlands. All our estimates are reported, including country dummies. As highlighted by MNvR, using differences controls for unobserved heterogeneity specific to the country-sector pair. Therefore, including country dummies essentially allows for different time trends across countries.

Our estimates are presented in Table 4 for each skill group separately (panels 1-3). In general, our baseline estimates are very close to the results in MNvR and indicate that an increase in ICT intensity was indeed associated with labour market polarisation. That is, an increase in ICT intensity has been associated with an increase in the wage share of high-skilled workers. Furthermore, a higher ICT intensity has been associated with a lower wage share of medium-skilled workers but had no impact on the wage share of low-skilled workers. The pattern appears to be stronger in the traded sector, where the coefficients are almost three times larger than the estimates for the total economy.

Our estimates are also of similar magnitude to MNvR. Column 1 in Table 4 reports that a percentage point increase in the ICT intensity increases the wage share of high-skilled workers by 0.48 pp. The corresponding value in MNvR is 0.47 pp.

Owing to the great heterogeneity in the base year 1980, which gives rise to a threat of mean reversal, we control for base year characteristics. Columns 2 and 5 show that the size of the effect decreases once we add the additional controls, but the results remain in line with the findings by MNvR. The exception is the estimates for the traded sectors, where the effect on medium-skill wage shares turns insignificant and the effect on the wage share for low-skilled workers becomes negative and significant. This suggests that digitisation may have not exclusively damaged labour market prospects for medium-skilled workers but potentially also for low-skilled workers.

We also revisit potential heterogeneity for different country groups. As highlighted by Goos, Manning and Salomons (2009), Western Europe has witnessed a smaller increase in wage polarisation than the US or the UK. Columns 3 and 5 show, similar to MNvR, smaller effects for the economies in continental Western Europe. However, once we control for base year characteristics, the negative impact on medium-skilled workers vanishes. Interestingly, the effect turns negative and significant at a 90% level for low-skilled workers in the traded sectors. These effects, however, are not very precisely estimated and are sensitive to robustness checks.

In the second part, we extend the analysis to the post-GFC period. Based on the KLEMS 2019 release, we estimate the model (1) for the period 2011-2016. Compared with the analysis for the period 1980 to 2004, the data cover 21 countries, but do not provide a breakdown for the manufacturing sector.

Table 4 / Estimation results 1980-2004

Panel 1: Wage share high-skilled workers

	(1)	(2)	(3)	(4)	(5)	(6)
ΔICT intensity	.479***	.318**	.26*	1.67***	1.127***	.68
	(.15)	(.126)	(.137)	(.36)	(.398)	(.513)
Δln GVA	4.158***	2.053*	3.366*	2.108*	1.088	1.651
	(1.06)	(1.121)	(1.756)	(1.083)	(1.068)	(1.452)
ΔNon-ICT intensity	-.082	-.058	-.082	.007	.034	.031
	(.053)	(.052)	(.07)	(.033)	(.029)	(.043)
Share HS, base year		.087	.075		.24*	.416***
		(.059)	(.077)		(.131)	(.141)
Share MS, base year		.137***	.103		.045	.099*
		(.052)	(.07)		(.047)	(.05)
ICT intensity, base year		.556***	.555***		.742	.141
		(.134)	(.165)		(.494)	(.56)
Observations	194	194	123	75	75	45
R-squared	.414	.493	.447	.848	.873	.906
countries	all	all	WE	all	all	WE
industries	all	all	all	traded	traded	traded
base year controls	no	yes	yes	no	yes	yes

Panel 2: Wage share medium-skilled workers

	(1)	(2)	(3)	(4)	(5)	(6)
ΔICT intensity	-.541**	-.253*	-.227	-3.45***	-.078	1.059
	(.264)	(.151)	(.157)	(.972)	(.561)	(.977)
Δln GVA	-7.541***	-2.037	-2.707	-1.939	-2.374*	-2.526
	(1.986)	(1.262)	(2.134)	(1.838)	(1.378)	(1.524)
ΔNon-ICT intensity	.111	-.022	-.01	-.148	-.09	-.085
	(.127)	(.091)	(.124)	(.125)	(.058)	(.076)
Share HS, base year		-.586***	-.515***		-.279	.272
		(.079)	(.097)		(.222)	(.408)
Share MS, base year		-.68***	-.606***		-.724***	-.764***
		(.072)	(.111)		(.067)	(.07)
ICT intensity, base year		-.263	-.166		.433	-.24
		(.175)	(.185)		(.88)	(.902)
Observations	194	194	123	75	75	45
R-squared	.384	.768	.705	.626	.9	.902
countries	all	all	WE	all	all	WE
industries	all	all	all	traded	traded	traded
base year controls	no	yes	yes	no	yes	yes

Panel 3: Wage share low-skilled workers

	(1)	(2)	(3)	(4)	(5)	(6)
ΔICT intensity	.062	-.064	-.033	1.78*	-1.05**	-1.739*
	(.192)	(.114)	(.136)	(.963)	(.505)	(1.015)
Δln GVA	3.383**	-.017	-.659	-.169	1.286	.875
	(1.549)	(.806)	(1.327)	(1.318)	(1.251)	(1.935)
ΔNon-ICT intensity	-.029	.08	.092	.141	.055	.054
	(.103)	(.07)	(.093)	(.124)	(.072)	(.103)
Share HS, base year		.499***	.44***		.039	-.689
		(.039)	(.049)		(.229)	(.488)
Share MS, base year		.543***	.503***		.679***	.665***
		(.059)	(.088)		(.088)	(.098)
ICT intensity, base year		-.293*	-.389*		-1.175	.099
		(.157)	(.206)		(1.038)	(1.146)
Observations	194	194	123	75	75	45
R-squared	.517	.858	.822	.627	.873	.865
countries	all	all	WE	all	all	WE
industries	all	all	all	traded	traded	traded
base year controls	no	yes	yes	no	yes	yes

Robust standard errors are in parentheses; *** p<.01, ** p<.05, * p<.1
Sources: EU KLEMS; own calculations.

The analysis for the period 2011-2016 shows a stark contrast to the preceding results. Panel 1 in Table 5, which shows the relationship between changes in ICT intensity and the wage share for high-skilled workers, suggests a negative relationship. The estimate based on our preferred model, however, is not statistically different from zero at the 90% level. Estimating the effects for different country samples, we find that the dynamics in Eastern European economies are likely to be the main driver behind for this finding. The estimates are insignificant for the country sample based on which we conducted the analysis for the period 1980-2004 (column 5, Table A3) and continental Western Europe (column 6, Table A3).

Table 5 / Estimation results 2011-2016

Panel 1: Wage share high-skilled workers

	(1)	(2)	(3)	(4)	(5)	(6)
ΔICT intensity	-.161*	-.136	-.327**	-.63**	-.689**	-.653*
	(.096)	(.092)	(.16)	(.271)	(.303)	(.344)
Δln GVA	1.044	.546	1.592	-1.927	-3.537	-2.938
	(1.199)	(1.211)	(1.571)	(1.982)	(2.273)	(2.593)
ΔNon-ICT intensity	0	.009	-.04	.014	.039	.02
	(.029)	(.028)	(.038)	(.048)	(.053)	(.066)
Observations	313	313	109	122	122	50
R-squared	.502	.545	.49	.593	.659	.573
countries	all NACE2	all NACE2	EE NACE2	all NACE2	all NACE2	EE NACE2
industries	all	all	all	non-tradable	non-tradable	non-tradable
base year controls	no	yes	yes	no	yes	yes

Robust standard errors are in parentheses; *** p<.01, ** p<.05, * p<.1

Panel 2: Wage share medium-skilled workers

	(1)	(2)	(3)	(4)	(5)	(6)
ΔICT intensity	.234**	.156*	.338**	.699**	.55**	.597*
	(.098)	(.084)	(.16)	(.268)	(.254)	(.353)
Δln GVA	-.862	-.051	-.275	3.108	3.843	3.949
	(1.156)	(1.179)	(1.701)	(2.239)	(2.387)	(2.8)
ΔNon-ICT intensity	.009	-.009	.021	-.012	-.028	-.036
	(.027)	(.026)	(.037)	(.048)	(.051)	(.066)
Observations	313	313	109	122	122	50
R-squared	.508	.548	.485	.587	.622	.564
countries	all NACE2	all NACE2	EE NACE2	all NACE2	all NACE2	EE NACE2
industries	all	all	all	non-tradable	non-tradable	non-tradable
base year controls	no	yes	yes	no	yes	yes

Robust standard errors are in parentheses; *** p<.01, ** p<.05, * p<.1

Panel 3: Wage share low-skilled workers

	(1)	(2)	(3)	(4)	(5)	(6)
ΔICT intensity	-.073	-.02	.07	-.069	.139	.056
	(.08)	(.041)	(.057)	(.128)	(.135)	(.079)
Δln GVA	-.182	-.496	-1.341***	-1.181*	-.306	-1.011**
	(.476)	(.455)	(.504)	(.613)	(.604)	(.496)
ΔNon-ICT intensity	-.008	.001	.022*	-.002	-.011	.016
	(.011)	(.01)	(.013)	(.016)	(.019)	(.015)
Observations	313	313	108	122	122	50
R-squared	.463	.635	.208	.538	.744	.234
countries	all NACE2	all NACE2	EE NACE2	all NACE2	all NACE2	EE NACE2
industries	all	all	all	non-tradable	non-tradable	non-tradable
base year controls	no	yes	yes	no	yes	yes

Robust standard errors are in parentheses; *** p<.01, ** p<.05, * p<.1
Sources: EU KLEMS; own calculations.

Panel 2 of Table 5 suggests that it was mainly medium-skilled workers who benefited in sectors that experienced a more intensive digitisation process as this increased the share for these workers. This is the opposite result to that we found in the analysis of the period 1980-2004. The effect of digitisation on low-skilled workers does not reveal any significant impact.

In the next step, we estimate effects for different sector groups. To follow MNvR, we separate sectors based on their exposure to international trade – see Table A1 in the Appendix for an overview. First, we define the tradable goods sector to encompass agriculture, mining and quarrying, and manufacturing. Second, in addition to the tradable goods sectors, we also define a broader sector group that includes service sectors exposed to international trade in addition to the goods sectors.[6] Based on the sectoral classifications, we find that is mainly the non-tradable sectors that drive the negative relationship between digitisation and changes in the high-skilled wage share. Columns 4-6 show that the size of the coefficients for the non-tradable sectors is at least double the estimates in columns 1-3 for the entire economy. Table A3 in the Appendix shows the results for the goods sectors and the tradable sectors, which suggest that digitisation did not alter wage shares in tradable sectors in the post-GFC period. Therefore, we conclude that the effects from digitisation observed in the total economy are mainly related to the non-tradable sector in particular in Eastern Europe and appear to have a smaller role in Western Europe.

3.3. ROBUSTNESS CHECKS

MNvR highlight that sectors which produce tradable goods could be more inclined to speed up the digitalisation process, owing to international competition. As MNvR and our analysis for 1980-2004 show, the estimates based on the sample of traded sectors are larger by comparison with the total economy, indicating a more positive effect for high-skilled workers and a more negative effect for medium-skilled workers in this sectoral group. Estimating the model for service sectors only suggests that digitisation played either no role or only a minor one in affecting wage shares – see Table A2.

Furthermore, as highlighted in the descriptive statistics, the financial intermediation and the post and telecommunications sector experienced by far the largest increases in ICT capital compensation in 1980-2004. In order to test the role of these sectors, we exclude them separately from our total economy analysis. We find that once we exclude the financial intermediation sector, no statistically significant impact of changes in ICT intensity on changes in the wage shares can be detected. Furthermore, we estimate the relationship for service sectors and find no significant relationship. This suggests that the driving force for the period 1980-2004 is indeed the tradable sector.

Finally, we test the robustness of the negative effect for low-skilled workers in the tradable sectors as suggested in panel 3 in Table 4. We find that the result is sensitive to changes in the sample. In particular, excluding the agriculture sector suggests that the results are not very robust.

For our analysis for the period 2011-2016, we find that, in particular, medium-skilled workers in the Eastern European non-tradable sectors benefited from digitisation. Further sensitivity analysis suggests that the public sector plays an important role in this relationship. Overall, however, the results appear sensitive towards changes in the sample composition. For example, dropping Estonia, Lithuania or Romania from the sample increases the size of the standard errors and the estimates turn insignificant.

6 Following Piton (2017), tradable sectors in addition to the tradable goods sectors encompass accommodation and food service activities; transportation and storage; administrative and support service activities; professional, scientific and technical activities; information and communication; and financial and insurance activities.

4. Conclusions

This paper investigates the impact of ICT capital accumulation on wage structures with respect to educational attainment levels (high, medium, low) for the recent period after the GFC and for a large set of countries, including the Eastern European economies. Methodologically, the paper draws on Michaels, Natraj and van Reenen (2014). We are able to corroborate their main findings for the period 1980 to 2004, indicating that adoption of ICT was accompanied by a reduction in the demand for medium-skilled workers but increased the demand for high-skilled workers, whereas it did not affect the demand for low-skilled workers. In this respect, we also point out that these results are mostly observable for the tradable industries.

Focusing on the more recent years, we find that a larger increase in ICT intensity was not associated with an increasing (decreasing) demand for high- (medium-) skilled workers during the period 2011-2016.[7] In addition, contrary to the findings for the period 1980-2004 for Western European economies, we find that a higher ICT intensity was associated with an increase (decrease) in medium- (high-) skilled workers for Eastern European economies between 2011-2016. The driving force behind this pattern appears to be developments in the service sectors. These results are in line with the more recent literature (see the discussion in the Introduction) indicating and explaining that the impact of ICT on demand for workers has changed, and also explaining the differentiated impact for economies adopting such technologies later.

7 Adarov and Stehrer (2019) point to significant differences in the underlying growth contributions of ICT capital and other production factors between the pre-crisis and post-crisis periods in value added and productivity growth.

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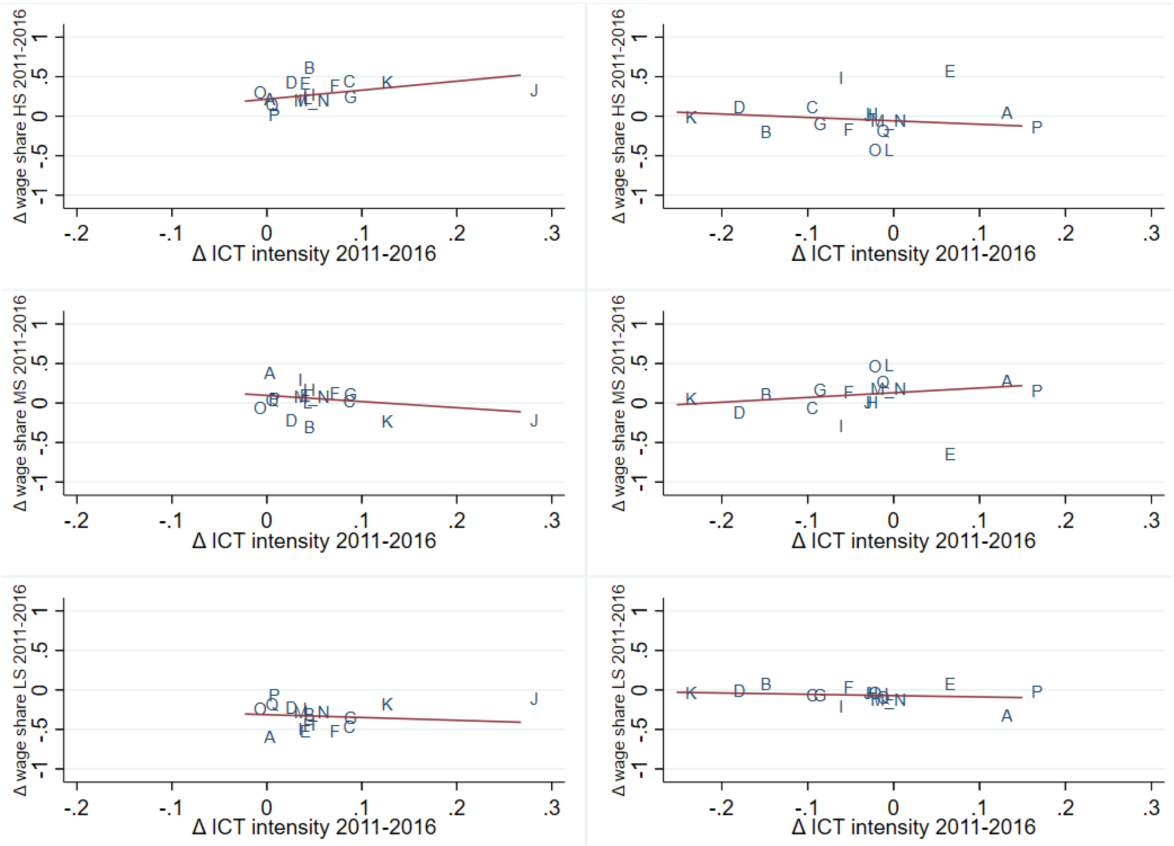
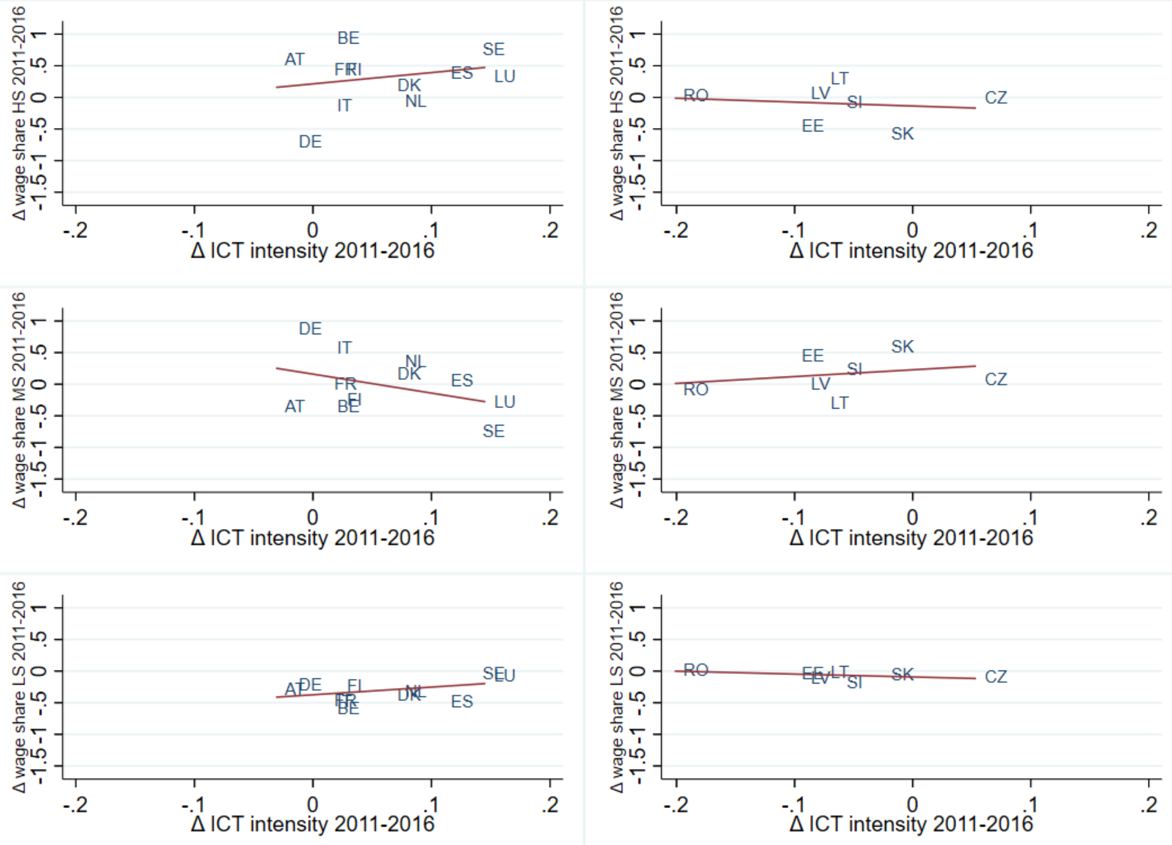
Appendix A – Supplementary figures and tables

Figure A1 / Sector-level correlation ICT intensity and wage share in Western Europe (left panel) and Eastern Europe (right panel), by skill group



Note: Excluding agriculture sector in Romania.

Figure A2 / country-level correlation ICT intensity and wage share in Western Europe (left panel) and Eastern Europe (right panel), by skill group



Sources: EU KLEMS; own calculations.

Table A1 / Sector group classification

Sector group	Period	Composition
Traded	1980-2004	Agriculture Manufacturing
Services	1980-2004	50 Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel 51 Wholesale trade and commission trade, except of motor vehicles and motorcycles 52 Retail trade, except of motor vehicles and motorcycles; repair of household goods 60-63 Transport and storage 64 Post and telecommunications 70 Real estate activities 71-74 Renting of machinery and equipment and other business activities E Electricity, gas and water supply F Construction H Hotels and restaurants J Financial intermediation L Public administration, defence, and compulsory social security M Education N Health and social work O Other community, social and personal services
Goods	2011-2016	Agriculture Mining and quarrying Manufacturing
Tradable sectors	2011-2016	Agriculture Mining and quarrying Manufacturing Accommodation and food service activities Transportation and storage Administrative and support service activities Professional, scientific and technical activities Information and communication Financial and insurance activities
Non-tradable sectors	2011-2016	Electricity, gas, steam and air conditioning supply Water supply; sewerage, waste management and remediation activities Construction Wholesale and retail trade; repair of motor vehicles and motorcycles, real estate activities Public administration and defence; compulsory social security, education Human health and social work activities

Sources: EU KLEMS; own elaborations.

Table A2 / Robustness checks: 1980-2004

Panel 1: Wage share high-skilled workers

	(1)	(2)	(3)	(4)	(5)	(6)
ΔICT intensity	.112	.059	.006	.393**	.24	.245
	(.196)	(.159)	(.2)	(.17)	(.151)	(.162)
Δln GVA	4.411***	2.487**	4.198**	3.152	.874	1.942
	(1.083)	(1.156)	(1.822)	(2.118)	(2.16)	(2.831)
ΔNon-ICT intensity	-.073	-.056	-.078	-.198**	-.164	-.282*
	(.053)	(.053)	(.073)	(.097)	(.123)	(.146)
Observations	185	185	117	96	96	63
R-squared	.395	.46	.419	.317	.392	.347
countries	all	all	WE	all	all	WE
industries	all excl J	all excl J	all excl J	service	service	service
base year controls	no	yes	yes	no	yes	yes

Robust standard errors are in parentheses; *** p<.01, ** p<.05, * p<.1

Panel 2: Wage share medium-skilled workers

	(1)	(2)	(3)	(4)	(5)	(6)
ΔICT intensity	.216	.044	.036	-.383	-.188	-.196
	(.359)	(.217)	(.319)	(.268)	(.172)	(.173)
Δln GVA	-7.848***	-2.315*	-3.304	-2.176	-1.501	-2.283
	(1.988)	(1.33)	(2.231)	(2.91)	(2.326)	(2.893)
ΔNon-ICT intensity	.09	-.023	-.015	.405***	.067	.193
	(.129)	(.094)	(.133)	(.111)	(.152)	(.181)
Observations	185	185	117	96	96	63
R-squared	.381	.76	.697	.47	.733	.715
countries	all	all	WE	all	all	WE
industries	all excl J	all excl J	all excl J	service	service	service
base year controls	no	yes	yes	no	yes	yes

Robust standard errors are in parentheses; *** p<.01, ** p<.05, * p<.1

Panel 3: Wage share low-skilled workers

	(1)	(2)	(3)	(4)	(5)	(6)
ΔICT intensity	-.328	-.103	-.042	-.01	-.052	-.05
	(.326)	(.207)	(.307)	(.193)	(.079)	(.096)
Δln GVA	3.437**	-.172	-.894	-.976	.627	.341
	(1.57)	(.813)	(1.373)	(1.959)	(1.073)	(1.508)
ΔNon-ICT intensity	-.017	.08	.093	-.208**	.097*	.089
	(.105)	(.072)	(.1)	(.082)	(.051)	(.057)
Observations	185	185	117	96	96	63
R-squared	.518	.861	.826	.671	.935	.937
countries	all	all	WE	all	all	WE
industries	all excl J	all excl J	all excl J	service	service	service
base year controls	no	yes	yes	no	yes	yes

Robust standard errors are in parentheses; *** p<.01, ** p<.05, * p<.1
Sources: EU KLEMS; own calculations.

Table A3 / Robustness checks: 2011-2016

Panel 1: Wage share high-skilled workers

	(1)	(2)	(3)	(4)	(5)	(6)
ΔICT intensity	.567*	-.112	.798	-.561	.055	-.174
	(.296)	(.136)	(.692)	(.338)	(.303)	(.205)
Δln GVA	-4.502	3.142	.76	5.033	-.725	-2.489
	(4.549)	(2.739)	(6.025)	(5.813)	(1.991)	(2.014)
ΔNon-ICT intensity	.067	-.048	-.075	-.156*	.022	.137***
	(.054)	(.07)	(.063)	(.087)	(.043)	(.046)
Observations	53	65	20	26	124	173
R-squared	.855	.701	.854	.736	.401	.602
countries	all NACE2	all NACE2	EE NACE2	EE NACE2	MNvR	WE NACE2
industries	goods	tradable sectors	goods	tradable sectors	all	all
base year controls	yes	yes	yes	yes	yes	yes

Robust standard errors are in parentheses; *** p<.01, ** p<.05, * p<.1

Panel 2: Wage share medium-skilled workers

	(1)	(2)	(3)	(4)	(5)	(6)
ΔICT intensity	-.757**	.118	-.928	.488	-.067	.073
	(.297)	(.143)	(.626)	(.341)	(.298)	(.184)
Δln GVA	5.064	-3.044	2.91	-4.269	1.222	2.276
	(3.733)	(3)	(5.159)	(5.923)	(1.85)	(1.723)
ΔNon-ICT intensity	-.09	.032	.018	.126	-.029	-.107**
	(.053)	(.072)	(.077)	(.097)	(.037)	(.041)
Observations	53	65	20	26	124	173
R-squared	.866	.735	.933	.692	.564	.666
countries	all NACE2	all NACE2	EE NACE2	EE NACE2	MNvR	WE NACE2
industries	goods	tradable sectors	goods	tradable sectors	all	all
base year controls	yes	yes	yes	yes	yes	yes

Robust standard errors are in parentheses; *** p<.01, ** p<.05, * p<.1

Panel 3: Wage share low-skilled workers

	(1)	(2)	(3)	(4)	(5)	(6)
ΔICT intensity	.189	-.006	.129	.073	.013	.101
	(.127)	(.065)	(.251)	(.11)	(.098)	(.087)
Δln GVA	-.563	-.098	-3.67	-.763	-.497	.213
	(2.129)	(1.088)	(2.907)	(1.796)	(.974)	(.913)
ΔNon-ICT intensity	.023	.016	.057	.03	.007	-.03
	(.03)	(.024)	(.057)	(.033)	(.016)	(.018)
Observations	53	65	20	26	124	173
R-squared	.931	.753	.961	.406	.565	.655
countries	all NACE2	all NACE2	EE NACE2	EE NACE2	MNvR	WE NACE2
industries	goods	tradable sectors	goods	tradable sectors	all	all
base year controls	yes	yes	yes	yes	yes	yes

Robust standard errors are in parentheses; *** p<.01, ** p<.05, * p<.1
Sources: EU KLEMS; own calculations.

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