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# Relative demand for highly skilled workers and use of different ICT technologies

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## ABSTRACT

This study investigates the relationship between several indicators of ICT usage and digitalization and the relative demand for highly skilled workers. The data are based on two-digit industry-level information on seven European countries for the period 2001–2010. For manufacturing industries, static fixed-effects models show that the share of employees with internet broadband access, the diffusion of mobile internet access and the use of enterprise resource planning (ERP) systems and automatic data exchange combined with electronic invoicing are all significantly and positively related to skill intensity in the industries observed. For service industries, only mobile internet usage intensity is significant. Specifically for manufacturing, a 10-point increase in the percentage of firms using ERP systems is associated with an increase in the share of highly skilled workers by 0.4 percentage points. These estimates indicate that the increase in ERP system usage during the period studied accounted for 30% of the increase in the share of workers with a tertiary degree across manufacturing industries and countries. The results are robust with respect to the estimation method and the potential endogeneity of ICT.

## KEYWORDS

Skill intensity; broadband-enabled employees; enterprise resource planning systems; skill-biased technological change

## JEL CLASSIFICATION

O33; J23; J24

## I. Introduction

The relationship between investments in information and communication technologies and the skill structure of a given workforce is a topic that is both very controversial and high on the policy and research agenda in the EU and the rest of the world. Specifically, researchers and policymakers are very interested in gaining a better understanding of the employment and skill-composition effects of the digital transformation. In particular, the economic literature has pointed out three main mechanisms by which ICT-enabled innovation affects employment.<sup>1</sup> First, ICT is an important driver of process innovation, which is often associated with labour saving (substitution effect). In fact, part of the literature has investigated the type of jobs that are at the highest risk of being substituted by ‘machines’ (Autor 2015; Autor, Levy, and Murnane 2003; Brynjolfsson and McAfee 2011, 2014; Frey and Osborne 2013; Goos and Manning 2007).

Second, new products – either in the ICT-producing or in ICT-using industries – tend to have a

positive effect on employment, to the extent that new demand arises and that other negative employment effects do not prevail.<sup>2</sup> A positive effect might also arise from lower prices as a result of labour-saving process innovation (though this might be partly counteracted by reduced demand due to lower income). These positive effects, along with other positive effects generated in general equilibrium, make up the compensation effect.

Third, the digitalization of the economy is also changing the composition of employment due to changes in the nature and requirements of jobs. In fact, ICT is a major driver of the knowledge economy, where the sources of competitive advantages relate more to innovative capacity than lower prices and intangible assets (such as skills and accumulated knowledge) are the main determinative factors.<sup>3</sup> The role of human capital as a driver of innovation and growth is confirmed by studies using macro data (see De La Fuente and Domenéch 2006), as well as by those using meso- and micro-level data (see Bartelsman, Dobbelaere, and Peters 2015; Mitra

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<sup>1</sup>For a review of the relationship between innovation and employment, see Vivarelli (2013, 2014).

<sup>2</sup>Product innovation can cause disruption and fierce competition within the same industry or across related industries, such that the employment gains in an industry could come at the cost of employment losses in industries producing substitute goods and services.

<sup>3</sup>Bartel and Lichtenberg (1987) argue that highly educated workers have a comparative advantage with respect to learning and implementing new technologies and that they tend to adopt innovations sooner than workers with less education.

and Jha 2015; Leiponen 2005; Piva and Vivarelli 2009).

In this article, we focus on the latter point in exploring the relationship between adoption and use of ICT and the skill structure of a given workforce. Earlier studies that have investigated the relationship between ICT investment or ICT capital and the relative demand for skilled workers have documented a significant and positive relationship (see Sabadash 2013 for a review). For instance, using industry-level data on US manufacturing and service industries for the period 1950–1990, Autor, Katz and Krueger (1998) find a significant and positive relationship between investment in computers and the industries' skill intensity. Using industry-level data on the US, Chun (2003) more recently finds that the use of information technology has accounted for almost 40% of the acceleration in demand for workers with a college degree since 1970. Haskel and Heden (1999) and Green, Felstead and Gallie (2003) find similar evidence for the UK (see also Falk and Seim 2001; Falk and Koebel 2004 for Germany; Piva and Vivarelli 2002 for Italy; Bayo-Moriones, Billón, and Lera-López 2008 for Spain; and O'Mahony, Robinson, and Vecchi 2008 for the US, UK, and France). Using EUKLEMS data on Spain, Pérez and López (2016) find that the complementarity between ICT and labour increases with the skill level of workers.

This positive relationship between higher skills and ICT (at the expense of unskilled workers) is commonly referred to as 'ICT-driven skill-biased technological change' (Michaels, Natraj, and Van Reenen 2010, 2014). However, one striking feature of the literature is that most studies employ ICT capital or investment or computer usage at work as the measure of ICT (see Autor, Katz, and Krueger 1998; Haskel and Heden 1999; O'Mahony, Robinson, and Vecchi 2008).

More recently, various authors have brought forward the idea that ICT might have a polarizing effect on the labour market, increasing the demand for both highly skilled and low-skilled workers while reducing the demand for medium-skilled employees.<sup>4</sup> This is confirmed by the work of Michaels, Natraj and Van Reenen (2010, 2014), who – using industry-level data drawn from the

EUKLEMS database for the United States, Japan and nine European countries for the period 1980–2004 – find that industries with a faster growth rate of ICT capital exhibit greater increases in the relative demand for highly educated workers while reducing the relative demand for workers with a medium level of education and having little effect on the demand for unskilled workers (i.e. ICT-driven job polarization).

One drawback of the majority of studies in this area is that they use ICT capital or ICT investment as indicators of ICT utilization. While this might be appropriate at the macro level, we believe that more granular data on the type of ICT utilization are necessary to explore the issue with meso- and micro-level data. Only a small number of studies use more complex indicators of ICT use, such as the adoption of e-business systems or the diffusion of broadband access among employees within and across firms, and estimate their impact on employment and the composition thereof. Akerman, Gaarder and Mogstad (2015) investigate whether the adoption of broadband internet leads to an increase in the productivity and labour outcomes of workers with different skill levels (i.e. skilled versus unskilled). Using Norwegian firm-level data, the authors show that the increased availability of broadband internet access improves the labour outcomes of skilled workers. In particular, a 10-percentage-point increase in broadband availability raises the wages of skilled workers in the local labour market by about 0.2%. In contrast, the authors find evidence of a decline in the wages of low-skilled individuals, but no significant effect on their employment rate. Using US county-level data for the period 1999–2007, Atasoy (2013) finds that broadband access is significantly and positively associated with an increase in the employment rate, with larger effects in counties with a high share of people with a college degree and in industries that employ more college graduates.

In this study, we extend the existing literature by relating skill intensity to measures of ICT usage intensity, such as broadband usage among employees and the diffusion of e-business systems (i.e. enterprise resource planning (ERP) and electronic invoicing systems). The use of ERP and electronic

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<sup>4</sup>Previous studies have only distinguished between two types of skills, making it impossible to investigate polarization.

invoicing systems is particularly interesting because they tend to raise productivity by improving the quality and speed of information (Abdinnour-Helm, Lengnick-Hall, and Lengnick-Hall 2003) to the benefit of managers and professionals, with unclear effects on unskilled and medium-skilled workers.

The structure of the article is as follows. Section II introduces the empirical model, while Section III presents the data and descriptive statistics. Section IV reveals the empirical results, and Section V concludes.

## II. Empirical model

In this study, we use industry-level data to study the relationship between skill intensity and different ICT indicators. We follow most of the related literature and measure skills by the share of workers with college or university education within a given industry. As for ICT, we depart from most of the literature (which uses expenditures on computing equipment or estimates of the ICT capital stock) in favour of using measures of different ICT applications at the industry level. The link between different information technology applications and workforce skill intensity can be analysed using a standard cost function framework (Berman, Bound, and Griliches 1994). The cost function is defined by two quasi-fixed factors of production, namely general capital and a measure of ICT usage. In addition, two variable inputs are included, namely university graduates ( $H$ ) and workers with intermediate or low education ( $M$ ). Total employment ( $L$ ) is equal to the sum of  $M$  and  $H$  ( $L = M + H$ ). In the case of a homothetic translog cost function with constant returns to scale and homogeneity of degree one in prices, Shepard's Lemma implies the following cost share equations, where the cost share of highly skilled labour is approximated by the skill intensity of the industry at hand<sup>5</sup>:

$$\frac{H_{ict}}{L_{ict}} = \alpha_{ic} + \beta_1 \ln K_{ict} + \beta_2 \ln VA_{ict} + ICT_{ict} \varphi + \lambda_t + \varepsilon_{ict} \quad (1)$$

where  $i = 1, \dots, N$  is industries at the two-digit level for a given country,  $c$ , and  $t = 2001, \dots, 2010$ .  $\alpha_{ic}$  denotes

fixed effects (country-industry pairs) and  $\lambda_t$  denotes the time effects.  $\ln$  denotes the natural logarithm. The dependent variable is the share of workers with a tertiary degree,  $H_{ict}/L_{ict}$ ;  $K_{ict}$  is the capital stock in constant prices and  $VA_{ict}$  is value added in constant prices.  $ICT$  is a vector of variables capturing the use of different ICT applications, including (1) the use of ERP systems; (2) the use of customer relationship management (CRM) systems; (3) the use of supply chain management (SCM) systems; (4) the use of automated data exchange (ADE) processes, including electronic invoicing and (5) the use of internal linkages between ICT systems. ERP software typically integrates data management for different company functions, such as planning, procurement, sales, marketing, finance and human resources (Hitt, Wu, and Zhou 2002). The introduction of ERP is often associated with significant organizational changes within a firm. CRM software aims to collect, process and analyse information related to a firm's customers (Hendricks, Singhal, and Stratman 2007). SCM software, meanwhile, is used to automatically share electronic information on procurement, sales, orders and inventory with customers and suppliers. ERP systems often include CRM and SCM applications, which makes it difficult to distinguish between the different e-business applications (Hendricks, Singhal, and Stratman 2007). In addition, firms are making increasing use of the e-invoicing functions of ERP systems (Kaliontzoglou, Boutsis, and Polemi 2006). E-invoicing leads to a change in the activities distributed within an accounting department, along with a possible reduction of the number of workers with such tasks.

The  $ICT$  vector also includes the proportion of internet-enabled employees and the percentage of workers with mobile internet access. The first variable is regarded as superior to many other commonly used broadband measures (such as the percentage of firms with broadband usage) because it measures not only the adoption of or access to broadband internet, but also the diffusion thereof within industries and over time (Hagsten 2016).

We expect to find a positive relationship between skill intensity and the variables capturing ICT/internet usage due to both production factors being complementary to each other. However, different types of ICT applications can have different effects. In fact,

<sup>5</sup>See Chennells and Van Reenen (2002) for the derivation of the skills share equation from the translog cost function.

Atasoy, Banker and Pavlou (2016) find that the employment effects of large-scale ICT applications (such as ERP systems) are significantly higher than those of small-scale ICT projects, such as the adoption of e-banking or the creation of a new website. Given that the previous literature finds that the link between employment and ICT applications differs by the type of ICT application in question, we include each ICT indicator separately.

The fixed-effects estimation of Equation (1) takes care of time-invariant firm/sector-specific effects, but it does not control for potential reversed causality. In other words, investment in ICT leads to higher demand for skilled workers, but increased human capital can also be an important precondition for ICT adoption and usage (as discussed in Section I). Moreover, skill intensity is also likely to be endogenous due to common unobservable factors affecting both ICT adoption and the demand for skills. Indeed, a number of studies show that the skill structure of a given workforce is an important determinant of ICT adoption and usage. Examples include Bresnahan, Brynjolfsson and Hitt (2002) for US firm-level data; Arvanitis (2005) for Swiss firm-level data; and Fabiani, Schivardi and Trento (2005) for Italian firm-level data. All this implies that we should control for the possibility of reverse causality and for spurious regression, which would induce correlation between the measures of ICT and the error terms.<sup>6</sup>

To do so, we use the system GMM panel data estimator developed by Blundell and Bond (1998), which takes into account the possible correlation of the ICT indicators with the error terms. This estimator is particularly useful for panel data with a relatively large number of cross-section units and a small time dimension, as is the case here. Given the high degree of persistence observed in the skill intensity variable, we opt for a dynamic adjustment process. Incorporating the partial adjustment mechanism into the static equation leads to the skill share equation in dynamic form:

$$\frac{H_{ict}}{L_{ict}} = \alpha_{ic} + \alpha_0 \left( \frac{H_{ict-1}}{L_{ict-1}} \right) + \beta_1 \ln K_{ict} + \beta_2 \ln VA_{ict} + ICT_{ict} \varphi + \lambda_t + \varepsilon_{ict} \quad (2)$$

where  $\alpha_{ic}$  denotes fixed effects (country-industry pairs) and  $\lambda_t$  time effects. The adjustment parameter can be calculated as  $\omega = (\alpha_0 - 1)$ . The long-run effect of the ICT variables on the skill share is obtained by  $\varphi/(1 - \hat{\alpha}_0)$ .

### III. Data and descriptive statistics

The data used for the analysis are drawn from the Micro Moments database (Bartelsman, Hagsten and Polder 2014). These data sets consist of data in micro-aggregated form (they are aggregated by industry, firm size or age, or both firm size and age). The company information is sourced from the national statistical offices of 12 European countries.<sup>7</sup> We use the information from the structural business statistics and the ICT/e-commerce survey. Skills are measured as the share of workers with post-upper secondary education, which means that those with a college or university degree are included in this definition (ISCED 5 and 6). The distinction between university and non-university education is often used in empirical studies (Fernandez Kranz 2006). However, information on educational attainment is only available for seven European countries (Denmark, Finland, France, the Netherlands, Norway, Sweden and the United Kingdom.). The data consists of an unbalanced panel data set across industries and countries for the period 2001–2010. Please note that for France, no data are available for the period 2002–2005. In this study, data at the NACE rev. 1.1 two-digit industry level are used. Data in NACE rev. 2 from 2008 onwards are converted to NACE rev. 1.1. This is possible because for 2008, data are available in both NACE classifications (see Table A2 in the Appendix for the industry classification). Value added is defined as gross output minus intermediate purchases of services and goods. The capital stock is based on fixed assets in constant prices (or alternatively, book value). Nominal prices (value added and capital) are deflated by EUKLEMS or WIOD two-digit price indexes. Employees are measured as full-time equivalents (DK, FI and SE) or head counts (FR, NL, NO and UK).

The variable *proportion of broadband internet-enabled employees* builds on information from the

<sup>6</sup>Given the small number of time periods, the large number of cross-section units and the fact that the key variables of interest are measured as shares, the so-called spurious regression problem can be ignored.

<sup>7</sup>The Micro Moments database includes micro-aggregated firm-level information for Austria, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Sweden, Slovenia and the UK.

**Table 1.** Descriptive statistics of the variables (in levels).

Year	Share of workers with a tertiary degree in %	% Broadband-enabled employees	Proportion of workers with mobile internet in %	% of firms with ERP	% of firms using automatic data exchange or electronic invoicing
Median across industries and countries					
<b>Manufacturing</b>					
2001	8.2	17.1	3.3	n.a	n.a
2002	8.3	22.6	10.2	n.a	n.a
2003	8.6	27.4	10.4	n.a	n.a
2004	9.3	34.6	14.8	n.a	n.a
2005	9.6	36.4	17.0	n.a	n.a
2006	9.7	36.4	19.4	52.9	53.7
2007	10.1	40.8	23.9	55.6	61.0
2008	10.6	40.3	25.8	58.3	56.9
2009	11.0	45.7	34.0	59.9	61.1
2010	10.6	43.7	37.4	76.5	68.2
<b>Services</b>					
2001	15.4	33.5	4.8	n.a	n.a
2002	12.8	37.4	11.4	n.a	n.a
2003	15.0	46.6	13.0	n.a	n.a
2004	14.9	51.3	16.9	n.a	n.a
2005	16.6	57.2	25.6	n.a	n.a
2006	17.3	57.0	29.6	22.4	54.0
2007	16.5	60.5	33.0	27.0	55.8
2008	18.4	59.8	39.7	31.9	56.9
2009	19.4	72.1	52.3	32.4	63.2
2010	18.5	65.2	52.9	50.4	66.1

Source: ESSLait Micro Moments database, unweighted across industries. Table contains data for DK, FI, FR, NL, NO, SE and UK. The sample of service industries includes NACE rev. 1.1, 50, 51, 52, 55, 60t3, 64, 65t7, 71t4, 72 and 73. Manufacturing contains 15a6, 20, 21, 22, 23a4, 25, 26, 27, 28, 29, 30a3, 31, 32, 34, 35 and 36a7. The sample consists of an unbalanced panel of industries and countries for the period 2001–2010. For 2002–2005, no data are available for France. ERP: Enterprise resource planning.

survey on ICT usage in firms (‘Community Survey on ICT Usage and E-Commerce in Enterprises’) (Hagsten 2016). The variable combines information based on two questions. The first is based on whether or not firms use a fast internet connection. Here, we define broadband usage as involving a digital subscriber line (DSL), asymmetric digital subscriber line (ADSL) or fixed-broadband internet connection (such as cable). Slower internet connections, such as dial-up modem or Integrated Services for Digital Network (ISDN) connections, are not included. The second question refers to the proportion of employees with computer usage and internet access: ‘How many persons employed used computers with access to the World Wide Web at least once a week in a given month?’<sup>8</sup> The measure of broadband internet-enabled employees goes beyond general computer usage in the workplace, which is often employed (Borghans and Ter ter Weel 2011). The percentage of workers with mobile internet access is constructed in a similar way. Besides mobile and broadband usage, we employ a measure of the percentage of firms using ERP systems, CRM systems or SCM systems. Finally, we include a measure of ADE or electronic invoicing (both receiving and sending e-invoices). All variables are aggregated at

the industry level for each country and time period (both weighted and unweighted aggregations).

Table 1 provides descriptive statistics based on unweighted data. We notice that the usage of different types of ICT increased steadily over time. Similarly, the share of workers with a tertiary degree increased continuously over time, with a larger increase in services than in manufacturing industries.

#### IV. Empirical results

Table 2 reports the fixed-effects estimates of the relationship between different types of ICT applications and the share of workers with a tertiary degree as in Equation (1). Separate estimation results are provided for manufacturing and service industries and for each of the four ICT indicators (see columns i–iv). The estimations are based on unbalanced two-digit industry panel data on seven European countries for the period 2001–2010.

For manufacturing industries, the results show that the percentage of firms with ERP systems is significantly and positively associated with the share of workers with a university degree even after controlling for fixed effects (country-industry pairs) and time effects. The shares of broadband-enabled workers and workers with mobile

<sup>8</sup>Source: Eurostat, Community Survey on ICT Usage and E-Commerce in Enterprises.

**Table 2.** Fixed-effects estimates of the impact of different types of information and communication technology on the share of workers with a tertiary degree.

	Manufacturing							
	(i)		(ii)		(iii)		(iv)	
	Coeff.	<i>t</i>	Coeff.	<i>t</i>	Coeff.	<i>t</i>	Coeff.	<i>t</i>
% of broadband internet-enabled employees	0.017**	2.10						
% of workers with mobile internet access			0.046***	7.55				
% of firms with ERP					0.030***	2.91		
% of firms with ADE or electronic invoicing							0.014***	3.23
In real capital stock in constant prices	-0.001	-0.60	0.002	0.65	-0.005	-0.98	-0.010***	-3.64
In real value added in constant prices	0.003	1.39	0.004*	1.95	0.000	-0.01	-0.002	-0.55
Year 2002 (ref. Category 2001 or 2006)	0.004*	1.84	0.000	0.10			0.002	0.59
Year 2003	0.009***	3.97	0.006***	2.68			0.011***	3.58
Year 2004	0.013***	5.27	0.009***	3.63			0.018***	6.27
Year 2005	0.019***	7.44	0.012***	4.93			0.025***	8.43
Year 2006	0.023***	8.68	0.013***	5.27			0.019***	5.21
Year 2007	0.028***	9.86	0.017***	6.37	0.010***	4.44	0.026***	7.02
Year 2008	0.029***	10.21	0.016***	5.92	0.011***	4.57	0.027***	7.61
Year 2009	0.034***	11.16	0.020***	6.55	0.015***	6.06	0.032***	8.64
Year 2010	0.034***	11.42	0.018***	5.46	0.015***	3.98	0.031***	7.66
Constant	0.070**	2.00	0.019	0.46	0.175**	2.36	0.259***	7.49
Number of observations	1039		911		431		688	
Number of groups (country 2-digit industry pairs)	112		112		112		112	
R <sup>2</sup>	0.46		0.47		0.25		0.46	
Market services								
	Coeff.	<i>t</i>	Coeff.	<i>t</i>	Coeff.	<i>t</i>	Coeff.	<i>t</i>
% of broadband internet-enabled employees	0.018	1.19						
% of workers with mobile internet access			0.042***	3.29				
% of firms with ERP					-0.003	-0.09		
% of firms with ADE or electronic invoicing							-0.040***	-3.43
log real capital stock in constant prices	-0.021***	-5.73	-0.024***	-6.82	-0.019***	-3.24	-0.026***	-6.71
log real value added in constant prices	0.019***	5.50	0.020***	6.08	0.032***	5.67	0.029***	7.51
Year 2002 (ref. Category 2001 or 2006)	0.006	1.07	0.002	0.33			0.009	0.90
Year 2003	0.012*	1.94	0.006	0.98			0.012	1.22
Year 2004	0.019***	3.04	0.011	1.59			0.023**	2.50
Year 2005	0.023***	3.42	0.013*	1.84			0.027***	2.90
Year 2006	0.022***	3.32	0.010	1.41			0.021*	1.94
Year 2007	0.022***	3.28	0.010	1.34	0.003	0.50	0.038***	3.65
Year 2008	0.032***	4.76	0.018**	2.34	0.012*	1.80	0.048***	4.54
Year 2009	0.029***	3.93	0.012	1.41	0.012	1.61	0.049***	4.47
Year 2010	0.036***	5.23	0.018**	2.16	0.036***	3.34	0.057***	5.02
Constant	0.219***	4.65	0.261***	5.94	0.024	0.39	0.159***	3.28
Number of observations	624		550		261		415	
Number of groups (country 2-digit industry pairs)	68		68		68		68	
R <sup>2</sup>	0.19		0.22		0.21		0.21	

\*, \*\* and \*\*\* are statistically significant at the 10%, 5% and 1% level, respectively. The estimation sample contains data for DK, FI, FR, NL, NO, SE and UK. The sample of service industries includes NACE rev. 1.1, 50, 51, 52, 55, 60t3, 65t67, 71a4, 72 and 73. Manufacturing contains 15a6, 20, 21, 22, 23a4, 25, 26, 27, 28, 29, 30a3, 31, 32, 34, 35 and 36a7. The sample consists of an unbalanced panel for the period 2001–2010, except for the specification with the ERP variable, which starts in 2006. For 2002–2005, no data are available for France. ERP: Enterprise resource planning; ADE: automated data exchange.

Source: ESSLait Micro Moments database.

internet access are also both significantly and positively associated with the skill intensity of the industry at hand. Interestingly, the share of firms using automatic data exchange or electronic invoicing is also significantly related to the share of highly skilled workers (at the 1% significance level). One possible explanation for this positive link is that automated electronic invoicing and payment systems make workers with intermediate and low education redundant, thereby increasing the demand for highly skilled workers.

For service industries, the use of mobile internet access is significant at the 1% level; the remaining

indicators are not significant at conventional significance levels or show the wrong sign, as is the case with automated electronic invoicing and payment systems. The results for manufacturing industries clearly indicate that increases in the share of broadband-enabled employees or usage of ERP systems promote the advancement of skills in the corresponding workforce (either by reducing the number of low- and medium-skilled workers, by raising demand for highly skilled workers or both). The results are consistent with the hypothesis that ICT complements highly skilled

workers and substitutes workers with low or medium skill levels.

Given the limited range of the standard deviation of the different ICT indicators (between 0.16 and 0.18), we can compare the size of the coefficients and conclude that ERP systems have the largest impact on the industry's skill intensity, followed by the share of workers with mobile internet access. In order to gain further insight into the magnitude of the correlations, we can then calculate the extent to which increased ERP usage contributes to skill advancement. A coefficient of 0.03 means that the increase in the use of ERP by 24 percentage points over the period 2006–2010 (from 53% to 77% based on unweighted data across manufacturing industries) accounts for an increase in the share of highly skilled workers by about 1 percentage point (calculated as  $0.007 = 0.03 \times 0.24$ ). Given the increase in the share of workers with a tertiary degree by 2.4 percentage points in manufacturing industries over the sample period, one can conclude that the increase in the percentage of firms using ERP systems accounts for 30% of the increase in the share of highly skilled workers. These calculations should be interpreted with caution, as they do not reflect causal relationships, but associations.

For manufacturing industries, the share of broadband-enabled workers also has a positive coefficient that is significant at the 5% level. The value of the coefficient is 0.017, indicating that the increase in the share of broadband-enabled employees by 20 percentage points between 2002 and 2010 accounted for a 0.34-percentage-point increase in the share of workers with a tertiary degree over the same period. The magnitude of this relation is relatively small given the increase in the share of workers with tertiary degree of 2.4 percentage points over the period.

Similarly, the coefficient of the share of workers with mobile internet access is highly significant, with a coefficient of 0.046. It is interesting to note that the contribution of the share of workers with mobile internet access is larger than that of broadband-enabled employees. Overall, the results indicate that skill intensity is more closely associated with ERP systems and mobile internet access than with broadband internet access. A similar conclusion can be drawn for automatic data exchange or electronic invoicing.

For manufacturing industries, the control variables are not relevant. Capital stock is not significant in the majority of cases, indicating that the capital–skill complementarity can be rejected in such industries. However, the coefficient on capital stock should be interpreted with caution because the capital measure is not based on the quality-adjusted price index for equipment (unlike in Krusell et al. 2000). Output, measured as value added in constant prices, exhibits a positive coefficient but is not significant at the conventional levels. The remaining ICT indicators (the percentage of firms using SCM and CRM systems) are not included in the final specification because they are never significant at the conventional levels. One explanation is that modern ERP systems often already include these business functions.

We now turn to the estimates of Equation (2), where we use the two-step system GMM methodology to estimate the impact of broadband penetration, ERP and mobile internet usage on the relative demand for skilled workers for the total sample (including manufacturing and service industries; see Table 3). Due to the small sample size for service industries, separate GMM estimations for services and manufacturing are not possible.

The GMM estimates use robust standard errors and treat the ICT indicators as predetermined. The Hansen *J*-test supports the validity of the instruments at the 1% significance level in all cases. In addition, an AR(2) test indicates that the residuals do not suffer from second-order serial correlation in all cases. The interpretation focuses on the short-run coefficients, as the long-run coefficients are relatively high due to the considerable high coefficient of the lagged share of workers with a university degree. We include contemporaneous and lagged values for the ICT indicators. The lagged values of the ICT indicators are never significant at the conventional levels, however, which is why the interpretation focuses on the coefficient on contemporaneous values.

The results show a statistically significant and positive relationship between skill intensity and the proportion of broadband-enabled employees. This implies that industries in which the share of workers using broadband internet connections increases will exhibit a greater change in skill intensity. The short-run coefficient is 0.043, indicating that an increase in the percentage of workers with broadband internet

**Table 3.** System GMM estimates of the impact of different types of information and communication technology on the share of workers with a tertiary degree (manufacturing and service industries).

	(i)		(ii)		(iii)		(iv)	
	Coeff.	<i>t</i>	Coeff.	<i>t</i>	Coeff.	<i>t</i>	Coeff.	<i>t</i>
Share of workers with tertiary degree ( <i>t</i> -1)	0.929***	15.99	0.927***	19.03	0.960***	35.00	0.961***	29.39
% of broadband-enabled employees ( <i>t</i> )	0.068***	2.73	0.043*	1.69				
% of broadband-enabled employees ( <i>t</i> -1)	-0.027	-1.32						
% of workers w. mobile internet access ( <i>t</i> )					0.035	1.42	0.024*	1.87
% of workers w. mobile internet access ( <i>t</i> -1)					-0.011	-0.41		
In capital stock constant prices ( <i>t</i> )	-0.003**	-2.53	-0.003***	-2.65	-0.002**	-2.52	-0.001	-1.37
In value added constant prices ( <i>t</i> )	0.007	1.61	0.006*	1.69	0.005	1.58	0.005	1.53
Year dummy variables	Yes		Yes		Yes		Yes	
Constant	-0.061	-1.08	-0.053	-0.94	-0.038	-0.97	-0.044	-0.96
Long-run semi-elasticity of the ICT variables	0.586***	5.05	0.595***	5.22	0.594***	3.02	0.615**	2.41
Number of observations	1327		1327		1177		1177	
Number of groups (country industry pairs)	180		180		180		180	
Number of instruments	151		174		174		151	
Hansen test of over-identifying restrictions ( <i>p</i> )	0.140		0.349		0.156		0.153	
Arellano-Bond test for AR(1) ( <i>p</i> )	0.124		0.134		0.366		0.366	
Arellano-Bond test for AR(2) ( <i>p</i> )	0.360		0.360		0.128		0.279	
	(v)		(vi)		(vii)		(viii)	
	Coeff.	<i>t</i>	Coeff.	<i>t</i>	Coeff.	<i>t</i>	Coeff.	<i>t</i>
Share of workers with tertiary degree ( <i>t</i> -1)	0.877***	10.20	0.881***	11.90	0.953***	24.30	0.931***	23.94
% of firms with ERP ( <i>t</i> )	0.013	0.34	0.038**	2.21				
% of firms with ERP ( <i>t</i> -1)	0.061	1.49						
% of firms w. ADE or electronic invoicing ( <i>t</i> )					0.052**	2.25		
% of firms w. ADE or electronic invoicing ( <i>t</i> -1)					-0.033***	-2.63	0.015	1.25
In capital stock in constant prices ( <i>t</i> )	-0.008	-1.42	-0.006	-1.37	-0.004*	-1.91	-0.002	-1.18
In value added in constant prices ( <i>t</i> )	0.013	1.53	0.010	1.37	0.003	1.04	0.007**	2.07
Year dummy variables	Yes		Yes		Yes		Yes	
Constant	-0.086	-0.95	-0.054	-0.82	0.022	0.46	-0.056	-1.00
Long-run semi-elasticity of the ICT variables	0.593	1.42	0.318	1.03	0.392	1.13	0.219	1.42
Number of observations	513		513		821		821	
Number of groups (country industry pairs)	180		180		180		180	
Number of instruments	136		167		134		150	
Hansen test of over-identifying restrictions ( <i>p</i> )	0.345		0.181		1.29		0.149	
Arellano-Bond test for AR(1) ( <i>p</i> )	0.226		0.308		0.03		0.123	
Arellano-Bond test for AR(2) ( <i>p</i> )	0.873		0.585		0.482		0.816	

\*\*\*, \*\* and \* denote significance at the 1%, 5% and 10% level, respectively. The group of industries includes NACE rev. 1.1: 15a6, 20, 21, 22, 23a4, 25, 26, 27, 28, 29, 30a3, 31, 32, 34, 35, 36a7, 50, 51, 52, 60t3, 64, 65t67, 71a4, 72 and 73. The country group includes DK, FI, FR, NL, NO, SE and UK. The sample period is 2003–2010, except for the specifications with ERP (2006–2010). The table reports two-step GMM results with the Windmeijer correction for small samples. The broadband internet variable is treated as predetermined (endogenous). The Hansen *J* test checks for the validity of instrumental variables (*p* value). The long-run impact can be calculated as the short-run coefficient divided by the adjustment parameter.

Source: ESSLait Micro Moments database and own calculations.

ERP: Enterprise resource planning; ADE: automated data exchange.

access by 10% is associated with an increase in skill intensity by 0.4 percentage points (based on specification ii). The share of firms using ERP systems and the percentage of workers with mobile internet access are also significant, with similar coefficients. Again, value added and capital do not play a role in determining increases in skill intensity over time. The coefficients of the lagged share of workers with a university degree range between 0.88 and 0.96, indicating a high degree of persistence in industry skill intensity.

We conduct several robustness checks. Following Berman, Bound and Griliches (1994), we estimate the relative demand for workers with a university degree by OLS in long (2-year) differences rather than using a fixed-effects model based on annual data. Unreported results for manufacturing industries again show that the ICT indicators are

significant in most cases. However, the standard errors based on OLS are higher than those of the fixed-effects estimator. Inspired by the studies showing that the introduction of new computer technologies into the workplace leads to new forms of work organization and other changes in organizational structure, thus increasing the demand for more skilled workers (Bartel, Ichniowski, and Shaw 2007; Battisti, Colombo, and Rabbiosi 2015; Chennells and Van Reenen 2002; Caroli and Van Reenen 2001; Piva, Santarelli, and Vivarelli 2005), we re-estimate the skill share equation using organizational change, a corresponding interaction term and different ICT indicators. However, results show that the percentage of firms whose organizational structures have changed is not significant (see Table A1 in the Appendix). Unreported results also show that the

interaction term between the ICT indicators and organizational change is not significant and that its inclusion does not lead to an increase in model fit.

## V. Conclusions

This study provides some initial estimates of the relationship between different ICT applications and the relative demand for workers with a tertiary degree. Previous studies have mainly investigated the relationship between investments in computers or other information technology hardware and increases in the share of skilled labour within a given industry. This study places special emphasis on specific ICT applications (such as e-business or enterprises systems) and other e-business applications (e.g. electronic invoicing) that are included in Eurostat's Community Survey on 'ICT Usage and E-Commerce in Enterprises' from 2006 onwards.

The data consist of unique, linked and internationally comparable industry-level information on seven European countries for the years 2001–2010. Fixed-effects estimations controlling for time effects show a positive and significant relationship between the share of workers with a tertiary degree and several ICT indicators. For manufacturing industries in particular, the share of broadband-enabled employees, the share of workers with mobile internet access and the use of ERP systems and electronic invoicing are all significantly and positively related to the share of workers with a university degree. For service industries, however, only the use of mobile internet is significant. For manufacturing industries, the association between the use of ERP systems and skill intensity is more pronounced than for the remaining ICT indicators. Across manufacturing industries on average, the increased usage of ERP systems accounts for 30% of the increase in the share of highly skilled workers over the period 2006–2010. Overall, the results indicate that internet usage and ERP systems are complements (rather than replacements) of highly skilled labour. Our results confirm those of previous studies on the first digital revolution. The current digital revolution also favours qualified workers. Our GMM estimates on the impact of broadband penetration, ERP systems and mobile internet access confirm the fixed-effects estimates.

This study has several limitations that should be mentioned. First, we use educational attainment as a

measure of skill despite the well-known fact that it is merely a proxy variable. Alternatively, employment can be disaggregated by occupations or tasks. Several studies suggest that routine jobs are likely to be more affected by ICT than non-routine positions. Future work should employ other measures, such as tasks or employment by occupational category. Second, it is not possible to distinguish between low and intermediate levels of education using the data available. Recent evidence shows that ICT has little impact on the relative demand for unskilled workers but has a strong negative impact on the share of those with intermediate education (Michaels, Natraj, and Van Reenen 2010, 2014).

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## Appendix

**Table A1.** Fixed-effects estimates of the impact of different types of information and communication technology and organizational change.

	(i)		(ii)		(iii)	
	Coeff.	t	Coeff.	t	Coeff.	t
% of broadband-enabled employees	0.024	1.64				
% of workers with mobile internet access			0.043***	3.48		
% of firms with ERP					0.060**	2.16
% of firms with changes in the organizational structure	−0.013	−0.90	−0.006	−0.33	0.019	0.50
Log real capital stock in constant prices	−0.024***	−7.16	−0.025***	−6.91	0.007	0.63
Log real value added in constant prices	0.016***	4.90	0.016***	4.58	0.008	1.32
Constant	0.258***	6.46	0.280***	6.29	−0.065	−0.54
Number of observations	769		691		348	
Number of groups (country 2-digit industry pairs)	191		191		190	
R <sup>2</sup>	0.23		0.21		0.27	

\*\*\*, \*\* and \* denote significance at the 1%, 5%, and 10% level, respectively. The group of industries includes NACE rev. 1.1: 15a6, 20, 21, 22, 23a4, 25, 26, 27, 28, 29, 30a3, 31, 32, 34, 35, 36a7, 50, 51, 52, 60t3, 64, 65t67, 71a4, 72, 73 and 91t2. The country group includes DK, FI, FR, NL, NO, SE and UK. The sample period is 2002–2010, with data used from each 2-year span therein. Note that the organizational change variable is based on the Community Innovation Survey and only available for each 2-year span (unlike the ICT indicators).

**Table A2.** EUKLEMS industry definitions (NACE 1.1).

	Two-digit EUKLEMS industry classification
TOT	Total economy
15t37	Manufacturing
15a6	Food, beverages and tobacco
17t9	Clothing
20	Wood and of wood and cork
21a2	Pulp, paper, publishing
21	Pulp, paper and paper
22	Publishing and printing
23t25	Refining, chemicals and rubber
23a4	Refining and chemicals
25	Rubber and plastics
26	Other non-metallic mineral
27a8	Metals and machinery
27	Basic metals
28	Fabricated metal
29t33	Machinery and equipment
29	Machinery, nec
30t3	Equipment
30a3	Office, accounting and computing machinery; sc. equipment
31	Electrical equipment
32	Electronic equipment
34a5	Motor vehicles and transport equipment
34	Motor vehicles, trailers and semi-trailers
35	Transport equipment
36a7	Misc manufacturing
40a1	Electricity, gas and water supply
45	Construction
50t74	Market services
50t5	Trade, hotels, restaurants
50t2	Wholesale and retail trade
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
55	Hotels and restaurants
60t4	Transport and communications
60t3	Transport
64	Post and telecommunications
65t7	Banking
70t4	Real estate and bus services
70	Real estate activities
71t4	Business services
71a4	Renting of machinery and equipment; other business services
72	Computer and related activities
73	Research and development
75t99	Social services
75	Public admin and defence; compulsory social security
80	Education
85	Health and social work
90t3	Personal services
90t3x	Personal services excl. media
921t2	Media activities

Source: [www.euklems.net/](http://www.euklems.net/).