Relative Demand for Highly Skilled Workers and Use of Different ICT Technologies

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accepted for publication in "Applied Economics"

Abstract

This study investigates the relationship between several indicators of ICT usage and digitalisation and the relative demand for highly skilled workers. The data is 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 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 per cent 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

Acknowledgements: We would like to thank Tyler Schaffner for excellent proof-reading. The first author is grateful to the Austrian National Bank (JF 16524) for financial support.

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1. 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 policy makers 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.[1] 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.[2] 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 digitalisation 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.[3] 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, 2016), as well as by those using meso- and micro-level data (see Bartelsman, Dobbelaere, and Peters, 2015; Mitra and Jha, 2015; Leiponen, 2005; Piva and Vivarelli, 2009).

In this paper, 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

[1] For a review of the relationship between innovation and employment, see Vivarelli (2013, 2014).
[2] 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.
[3] 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.

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 per cent 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 et al., 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 polarising effect on the labour market, increasing the demand for both highly skilled and low-skilled workers while reducing the demand for medium-skilled employees.[4] 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 US, 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 polarisation).

One drawback of the majority of studies in this area is that they use ICT capital or ICT investment as indicators of ICT utilisation. While this might be appropriate at the macro level, we believe that more granular data on the type of ICT utilisation is 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

[4] Previous studies have only distinguished between two types of skills, making it impossible to investigate polarisation.

outcomes of workers with different skill levels (i.e. skilled vs. 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 per cent. 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 and electronic invoicing systems). The use of ERP and electronic 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 paper is as follows. Section 2 introduces the empirical model, while Section 3 presents the data and descriptive statistics. Section 4 reveals the empirical results, and Section 5 concludes.

2. 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:[5]

$$H_{ict} / L_{ict} = \alpha_{ic} + \beta_1 \ln K_{ict} + \beta_2 \ln VA_{ict} + ICT_{ict}\phi + \lambda_t + \varepsilon_{ict}, \qquad [1]$$

where *i=1,..,N* are industries at the two-digit level for a given country, *c*, and *t*=2001, ,,..,2010. α_{ic} denotes fixed effects (country-industry pairs) and λ_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 organisational changes within a firm. CRM software aims to collect, process, and analyse information related to a firm's customers (Hendricks, Singhal, and Stratman, 2007). Supply chain management (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, Boutsi 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.

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, Atasoy, Banker, and Pavlou (2016) find that the employment effects of large-scale ICT applications

[5] See Chennells and Van Reenen (2002) for the derivation of the skills share equation from the translog cost function.

(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 eq [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 1). 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.[6]

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:

$$H_{ict} / L_{ict} = \alpha_{ic} + \alpha_0 H_{ict-1} / L_{ict-1} + \beta_1 \ln K_{ict} + \beta_2 \ln VA_{ict} + ICT_{ict}\phi + \lambda_t + \varepsilon_{ict} \ , \qquad [2]$$

where α_{ic} denotes fixed effects (country-industry pairs) and λ_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: $\phi / (1 - \hat{\alpha}_0)$.

3. Data and descriptive statistics

The data used for the analysis is drawn from the Micro Moments database (MMD). These datasets 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

[6] 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.

statistical offices of 14 European countries.[7] We also 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 (DK, FI, FR, NL, NO, SE, and UK). 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 is available for the period 2002-2005. In this study, data at the NACE rev 1.1 two-digit industry level is used. Data in NACE rev. 2 from 2008 onwards is converted to NACE rev 1.1. This is possible because for 2008, data is available in both NACE classifications (see Table 5 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 employee*s builds on information from the survey on ICT usage in firms ("Community Survey on ICT Usage and E-Commerce in Enterprises"). 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 DSL, ADSL, or fixed-broadband internet connection (such as cable). Slower internet connections, such as dial-up modem or 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?".[8] The measure of broadband internet-enabled employees goes beyond general computer usage in the workplace, which is often employed (Borghans and 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 enterprise resource planning (ERP) systems, customer relationship management (CRM) systems, or supply chain management (SCM) systems. Finally, we include a measure of automated data exchange (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).

[7] The Micro Moments database includes micro-aggregated firm-level information for Austria, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Sweden, Slovenia, and the United Kingdom.
[8] Source: Eurostat, Community Survey on ICT Usage and E-Commerce in Enterprises.

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.

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				
	manufacturing				
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
	services				
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 is available for France.

4. 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 eq [1]. Separate estimation results are provided for manufacturing and service industries and for each of the four ICT indicators (see columns i to iv). The estimations are based on unbalanced two-digit industry panel data on seven European countries for the period 2001-2010.

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.		t	coeff.		t	coeff.		t	coeff.		t
% 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
ln real capital stock in constant prices	-0.001		-0.60	0.002		0.65	-0.005		-0.98	-0.010		-3.64
ln 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
# of observations	1039			911			431			688		
# of groups (country 2 digit industry pairs)	112			112			112			112		
R^2	0.46			0.47			0.25			0.46		
						market services						
	coeff.		t	coeff.		t	coeff.		t	coeff.		t
% of broadband internet-enabled employeest	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
# of observations	624			550			261			415		
# of groups (country 2 digit industry pairs)	68			68			68			68		
R^2	0.19			0.22			0.21			0.21		

Notes: *, **, and *** are statistically significant at the 10, 5, and 1 per cent 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 is available for France.

Source: ESSLait Micro Moments database.

For manufacturing industries, the results show that the percentage of firms with enterprise resource planning 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 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 one per cent 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 one per cent 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 firms that provide a broadband connection to their employees and use 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 enterprise resource planning 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 per cent to 77 per cent based on unweighted data across manufacturing industries) accounts for an increase in the share of highly skilled workers by about one percentage point (calculated as 0.007=0.03 X 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 per cent 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 five per cent 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 2012 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, Ohanian, Ríos-Rull, and Violante, 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 supply chain management and customer relationship management 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.

Table 3: System GMM estimates of the impact of broadband internet enabled employees on the share of workers with a tertiary degree (manufacturing and service industries)

	(i)		(ii)		(iii)		(iv)	
	coeff.	t	coeff.	t	coeff.	t	coeff.	t
share of workers with tertiary degree (t-1)	0.929***	15.99	0.927***	19.03	0.960***	35.00	0.961***	29.39
% of broadband enabled employees (t)	0.068**	2.73	0.043*	1.69				
% of broadband enabled employees (t-1)	-0.027	-1.32						
% of workers w. mobile internet access (t)					0.035	1.42	0.024*	1.87
% of workers w. mobile internet access (t-1)					-0.011	-0.41		
ln capital stock constant prices (t)	-0.003**	-2.53	-0.003***	-2.65	-0.002**	-2.52	-0.001	-1.37
ln value added constant prices (t)	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	0.586**	5.05	0.595***	5.22	0.594***	3.02	0.615**	2.41
# of observations	1327		1327		1177		1177	
# of groups (country industry pairs)	180		180		180		180	
number of instruments	151		174		174		151	
Hansen test of over-identifying restrictions (p)	0.140		0.349		0.156		0.153	
Arellano-Bond test for AR(1)	0.124		0.134		0.366		0.366	
Arellano-Bond test for AR(2)	0.360		0.360		0.128		0.279	
		(v)		(vi)		(vii)		(viii)
	coeff.	t	coeff.	t	coeff.	t	coeff.	t
share of workers with tertiary degree (t-1)	0.877***	10.2	0.881***	11.9	0.953***	24.30	0.931***	23.94
% of firms with ERP (t)	0.013	0.34	0.038**	2.21				
% of firms with ERP (t-1)	0.061	1.49						
% of firms w. ADE or electronic invoicing (t)					0.052**	2.25		
% of firms w. ADE or electronic invoicing (t-1)					-0.033***	-2.63	0.015	1.25
ln capital stock in constant prices (t)	-0.008	-1.42	-0.006	-1.37	-0.004*	-1.91	-0.002	-1.18
ln value added in constant prices (t)	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	0.593	1.42	0.318	1.03	0.392	1.13	0.219	1.42
# of observations	513		513		821		821	
# of groups (country industry pairs)	180		180		180		180	
number of instruments	136		167		134		150	
Hansen test of over-identifying restrictions (p)	0.345		0.181		1.29		0.149	
Arellano-Bond test for AR(1)	0.226		0.308		0.03		0.123	
Arellano-Bond test for AR(2)	0.873		0.585		0.482		0.816	

Note: ***, **, and * denote significance at the 1, 5, and 10 per cent 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.

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 one per cent 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 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 access by 10 per cent 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 (two-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 organisation and other changes in organisational 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 organisational change, a corresponding interaction term, and different ICT indicators. However, unreported results show that the percentage of firms whose organisational structures have changed is not significant (see Table 4 in the appendix). Unreported results also show that the interaction term between the ICT indicators and organisational change is not significant, and that its inclusion does not lead to an increase in model fit.

5. 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 places special emphasis on specific ICT applications (such as e-business or enterprises systems) and other e-business applications (electronic invoicing, for example) that are included in Eurostat's Community Survey on "ICT Usage and E-Commerce in Enterprises" from 2006 onwards.

The data consists 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 enterprise resource planning 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 per cent 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, enterprise resource planning 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).

Literature

Abdinnour-Helm, S., M. L., Lengnick-Hall, and C. A. Lengnick-Hall 2003. "Pre-implementation attitudes and organizational readiness for implementing an enterprise resource planning system." *European Journal of Operational Research* 146 (2): 258–273.

Akerman, A., I. Gaarder, and M. Mogstad 2015. "*The skill complementarity of broadband internet.*" *The Quarterly Journal of Economics* 130 (4): 1781–1824.

Arvanitis, S. 2005. "Computerization, workplace organization, skilled labour and firm productivity: Evidence for the Swiss business sector." *Economics of Innovation and New Technology 14* (4):, 225–249.

Atasoy, H. 2013. "Effects of Broadband Internet Expansion on Labor Market Outcomes. " *Industrial and Labor Relations Review* 66 (2): 315–345.

Atasoy, H., R. D, Banker, and P. A. Pavlou 2016. "On the Longitudinal Effects of IT Use on Firm-Level Employment." *Information Systems Research* 27 (1): 6–26.

Autor, D. H. 2015. "Why are there still so many jobs? the history and future of workplace automation." *The Journal of Economic Perspectives* 29 (3), 3–30.

Autor, D. H., Katz, L. F., and A. B. Krueger. 1998. "Computing Inequality: Have Computers Changed the Labor Market? " *Quarterly Journal of Economics* 113 (4): 1169–1213.

Autor, D.H ,F Levy, and R. J Murnane 2003. "The Skill Content of Recent Technological Change: An Empirical Exploration. *Quarterly Journal of Economics* 118 (4), 1279–1334.

Bartel, A. P., and F. R. Lichtenberg, 1987. "The comparative advantage of educated workers in implementing new technology." *The Review of Economics and Statistics* 69: 1–11.

Bartel, A.P, C. Ichniowski, and K. Shaw 2007. "How does information technology affect productivity? Plant-level comparisons of product innovation, process improvement and worker skills." *Quarterly Journal of Economics* 122 (4): 1721–1758.

Bartelsman, E., S. Dobbelaere, and B. Peters 2015. "Allocation of human capital and innovation at the frontier: firm-level evidence on Germany and the Netherlands." *Industrial and Corporate Change* 24 (5): 875–949.

Bayo-Moriones, A., M. Billón and F., Lera-López 2008. "Skills, technology and organisational innovation in Spanish firms." *International Journal of Manpower 29* (2): 122–145.

Battisti, G., M. G. Colombo, and L. Rabbiosi 2015. "Simultaneous versus sequential complementarity in the adoption of technological and organizational innovations: the case of innovations in the design sphere." *Industrial and Corporate Change* 24 (2): 345–382.

Berman, E., J. Bound, and Z. Griliches 1994. "Changes in the Demand for Skilled Labor within US Manufacturing: Evidence from the Annual Survey of Manufacturers." *The Quarterly Journal of Economics* 109 (2): 367–397.

Blundell, R., and S. Bond 1998. "Initial conditions and moment restrictions in dynamic panel data models." *Journal of Econometrics* 87 (1): 115–143.

Borghans, L., & B. ter Weel 2011. "Computers, skills and wages." *Applied Economics* 43 (29), 4607–4622.

Bresnahan, T. F., E. Brynjolfsson, and L. M. Hitt 2002. "Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence." *The Quarterly Journal of Economics 117* (1): 339–376.

Brynjolfsson, E. and A. McAfee 2011 *Race Against The Machine: How the Digital Revolution is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy*. Digital Frontier Press.

Brynjolfsson E. and A. McAfee 2014. *The Second Machine Age,* W. W. Norton & Company.

Caroli E. and J. Van Reenen 2001. "Skill biased organisational change? Evidence from a panel of British and French establishments." *The Quarterly Journal of Economics* 116 (4): 1449–92.

Chennells L. and J. Van Reenen 2002. "Has Technology hurt the less skilled workers? An econometric survey of the effects of technical change on the structure of pay and jobs." in L'Horty Y., Greenan N., and Mairesse J. eds, *Productivity, Inequality and the Digital Economy*, MIT Press, 175–225.

Chun, H. 2003. "Information technology and the demand for educated workers: disentangling the impacts of adoption versus use." *Review of Economics and Statistics* 85 (1): 1–8.

De la Fuente, A. 2011. "Human capital and productivity", UFAE and IAE Working Papers 860.11, Unitat de Fonaments de l'Anàlisi Econòmica (UAB) and Institut d'Anàlisi Econòmica (CSIC).

De La Fuente Á, and Domenéch A., 2006. "Human capital in growth regressions: how much difference does data quality make?", *Journal of the European Economic Association* 4 (1): 1–36.

Fabiani, S., F. Schivardi, and S. Trento 2005. "ICT adoption in Italian manufacturing: firm-level evidence." *Industrial and Corporate Change* 14 (2): 225–249.

Falk, M., and B. M. Koebel 2004. "The impact of office machinery, and computer capital on the demand for heterogeneous labour." *Labour Economics* 11 (1): 99–117.

Falk, M., and K. Seim 2001. "The Impact Of Information Technology On High-Skilled Labor In Services: Evidence From Firm-Level Panel Data." *Economics of Innovation and New Technology* 10 (4): 289–323.

Fernandez Kranz, D. 2006. "Why has wage inequality increased more in the USA than in Europe? An empirical investigation of the demand and supply of skill." *Applied Economics* 38 (7), 771–788.

Frey, C.B., and M.A Osborne 2013. The future of employment: how susceptible are jobs to computerisation? Oxford University, Sept. 17, 2013, http://www.oxfordmartin.ox.ac.uk/downloads/ academic/The_Future_of_Employment.pdf, last accessed April 2014

Goos, M., and A. Manning 2007. Lousy and Lovely Jobs: The Rising Polarization of Work in Britain; The *Review of Economics and Statistics*; 89 (1), 118–133.

Green, F., A. Felstead, and D. Gallie 2003. "Computers and the changing skill-intensity of jobs." *Applied Economics 35*(14): 1561–1576.

Haskel, J., and Y. Heden.1999. "Computers and the Demand for Skilled Labor: Industry and Establishment-level: Evidence for the UK." *Economic Journal* 109: 68–79.

Hendricks, K. B., V. R. Singhal, and J. K. Stratman 2007. "The impact of enterprise systems on corporate performance: A study of ERP, SCM, and CRM system implementations." *Journal of Operations Management* 25 (1): 65–82.

Hitt, L. M., D. J. Wu, and X. Zhou 2002. "Investment in enterprise resource planning: Business impact and productivity measures." *Journal of Management Information Systems* 19 (1): 71–98.

Kaliontzoglou, A., P. Boutsi and D. Polemi 2006. "eInvoke: Secure e-Invoicing based on web services". *Electronic Commerce Research* 6 (3-4), 337–353.

Krusell, P., L. E Ohanian, J. V.Ríos-Rull, and G. L. Violante 2000. "Capital-skill complementarity and inequality: A macroeconomic analysis." *Econometrica* 68 (5): 1029–1053.

Leiponen, A. 2005. "Skills and innovation." *International Journal of Industrial Organization*, 23 (5): 303–323.

Michaels, G., A. Natraj, and J. Van Reenen.. 2010. "*Has ICT polarized skill demand? Evidence from eleven countries over 25 years.*" (No. w16138). National Bureau of Economic Research.

Michaels, G., A. Natraj and J. Van Reenen 2014. "Has ICT polarized skill demand? Evidence from eleven countries over twenty-five years." *Review of Economics and Statistics* 96 (1): 60–77.

Mitra, A., and A. K. Jha 2015. "Innovation and employment: a firm level study of Indian industries. *Eurasian Business Review*, 5(1): 45–71.

O'Mahony, M., C. Robinson, and M. Vecchi 2008. "The impact of ICT on the demand for skilled labour: a cross-country comparison." *Labour Economics* 15 (6): 1435–1450.

Pérez, M. A. H., and J. R. López 2016. "Labor demand and ICT adoption in Spain." *Telecommunications Policy* 40 (5): 450–470.

Piva, M., E. Santarelli, and M. Vivarelli 2005. "The skill bias effect of technological and organisational change: Evidence and policy implications." *Research Policy 34* (2): 141–157.

Piva, M., and M. Vivarelli 2002. "The skill bias: comparative evidence and an econometric test." *International Review of Applied Economics 16* (3): 347–357..

Piva, M., and M. Vivarelli 2009. "The role of skills as a major driver of corporate R&D." *International Journal of Manpower 30* (8): 835–852.

Sabadash A. 2013. "*ICT-induced Technological Progress and Employment: a Happy Marriage Or a Dangerous Liaison?: A Literature Review.*" IPTS, European Commission, Publications Office.

Vivarelli, M. 2013. "Technology, employment and skills: an interpretative framework." *Eurasian Business Review* 3 (1): 66–89.

Vivarelli, M. 2014. "Innovation, Employment and Skills in Advanced and Developing Countries: A Survey of Economic Literature." *Journal of Economic Issues 48* (1): 123–154.

Appendix

Table 4: Fixed effects estimates of the impact of different types of information and communication technology and organisational 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 organisational 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 const. 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
# of observations	769			691			348		
# of groups (country 2 digit industry pairs)	191			191			190		
R^2	0.23			0.21			0.27		

Note: ***, **, and * denote significance at the 1, 5, and 10 per cent 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 two-year span therein. Note that the organisational change variable is based on the Community Innovation Survey and only available for each two-year span (unlike the ICT indicators).

Table 5. 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. equipement.
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/*