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Empirical Studies on the Impacts of ICT Usage in Europe

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Preface

This report was prepared in the context of the three-year research project on *European Innovation Policies for the Digital Shift* (EURIPIDIS) jointly launched in 2013 by JRC-IPTS and DG CONNECT of the European Commission in order to improve understanding of innovation in the ICT sector and of ICT-enabled innovation in the rest of the economy.[1]

The purpose of the EURIPIDIS project is to provide evidence-based support to the policies, instruments and measurement needs of DG CONNECT for enhancing ICT Innovation in Europe, in the context of the Digital Agenda for Europe and of the ICT priority of Horizon 2020. It focuses on the improvement of the transfer of best research ideas to the market.

EURIPIDIS aims are:

1 to better understand how ICT innovation works, at the level of actors such as firms, and also of the ICT "innovation system" in the EU;

2 to assess the EU's current ICT innovation performance, by attempting to measure ICT innovation in Europe and measuring the impact of existing policies and instruments (such as FP7 and Horizon 2020); and

3 to explore and suggest how policy makers could make ICT innovation in the EU work better.

This report has three sections and a key feature of our empirical analysis is the use of several types of advanced ICT activities such as enterprise resource planning systems, mobile internet access and e-commerce practices.

The first section presents new empirical evidence regarding the impact of ICT/E-commerce activities on industry performance in Europe measured as employment and labour productivity growth. The data consists of multi-country industry level data for 14 European countries for the period 2002-2010. The main result of this section is that the increase in ICT/e-commerce activities over time has not lead to a decline in jobs. This holds true for both manufacturing and service industries. In contrast, the different types of ICT activities are significantly related to labour productivity. However, the sign and significance of the relationships vary across different types of ICT activities and also vary over time with lower magnitude for the more recent period.

The second section looks at 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 data for seven European countries for the period 2002-2010. For manufacturing industries, our estimates show that broadband connected employees, diffusion of mobile internet, use of enterprise resource planning systems and electronic invoicing are all significantly positively related to the industries' skill intensity. For service industries only mobile internet usage is significant. These estimates indicate that the increase in ERP systems during the period studied accounts for 25% 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 when accounting for endogeneity of ICT.

The third section investigates the relationship between technological and organisational innovations, and ICT usage/e-commerce and internet technologies. The data is based on disaggregated data by firm size/industry for 12 European countries for the period 2002-2010. The empirical results show that the sales share of new market products is significantly positively related with both the percentage of workers with mobile internet access and e-procurement activities. Sharing electronic data also contributes to product innovations. We also find that organisational change and enterprise resource planning

[1] For more information, see the project web site: http://is.jrc.ec.europa.eu/pages/ISG/EURIPIDIS/EURIPIDIS.index.html

systems are significantly positively related, indicating that the changes in the organisational structure are critical for successful ERP implementation.

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Abstract

This report consists of three studies. The first study presents new empirical evidence on the impact of ICT/e-commerce activities on industry performance measured as employment and labour productivity growth. The second study presents new empirical evidence on the impact of ICT/e-commerce indicators on the skill intensity measured as the share of workers with a university degree. The third study investigates whether and to what extent ICT/e-commerce activities are enablers of innovation activities. The data consists of micro-aggregated data on firms drawn from the production, ICT and CIS survey.

Study 1. Impact of ICT activities on employment growth and industry performance in Europe

1.1 Abstract

This study presents new empirical evidence regarding the impact of ICT/E-commerce activities on industry performance in Europe measured as employment and labour productivity growth. The data consists of multi-country industry level data for 14 European countries for the period 2002-2010. A key feature of the empirical analysis is the use of several types of advanced ICT activities such as enterprise resource planning systems, mobile internet access and e-commerce practices. The main result of the study is that the increase in ICT/e-commerce activities over time has not lead to a decline in jobs. This holds true for both manufacturing and service industries. In contrast, the different types of ICT activities are significantly related to labour productivity. However, the sign and significance of the relationships vary across different types of ICT activities and also vary over time with lower magnitude for the more recent period.

1.2 Introduction

There has been ongoing discussion about the impacts of different ICT applications and ecommerce practices in Europe. As the use of ICT applications are reaching the saturation level it is often stated that returns to ICT are diminishing over time (Acemoglu et al. 2014).[2] Similarly, Linstone and Devezas (2012) question whether the recent wave of technological ICT related innovations exhibits the same productivity enhancing effect as past technological revolutions. Furthermore, there is debate raging whether increased ICT usage destroys jobs (Brynjolfsson and McAfee, 2011). More recently, based on aggregate data for 27 EU countries, Evangelista et al. (2014) find that ICT usage has a positive and significant impact on labour productivity. At the same time several other dimensions of digitalization lead to an increase in manufacturing employment. So far there is no consensus about the effects of different types of ICT on employment and labour productivity.

In recent years there has been a shift towards more complex and sophisticated forms of ICT and internet applications. In general, the focus of research is not only on the impacts of ICT capital or infrastructure but also the effects of complex ICT applications, e-commerce activities, digitalization and the indirect impact of ICT (Evangelista et al. 2014).

This study provides new empirical evidence on the relationship between different ICT/e-commerce activities and both labour demand and labour productivity using data for 14 European countries. Unlike previous studies that mainly rely on cross-section methods, this study uses both a specification in first-differences and dynamic panel data methods to investigate the impacts of ICT. In particular, we consider different types of ICT capacities ranging from having websites and broadband internet to complex systems like enterprise resource planning systems. Special emphasis is put on the magnitude of the relationships.

The empirical model is estimated using OLS in long differences and dynamic panel data methods which account for group effects (by industry-firm size pairs for a given country). The use of dynamic panel data methods makes it possible to treat the ICT indicators as predetermined. Lagged levels of the variables and lagged difference of the variables are used as instruments. The data consists of unique panel data for several EU countries (the so-called Micro Moments Database constructed within the ESSlait project, see Bartelsman, Hagsten and Polder, 2014). The dimensions emphasized here are industry affiliation (measured as broad industry groups) and firm size for the period 2002-2010, and the two-digit industry level data set.

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2 See Figure 2 in appendix for the diffusion of different ICT applications over time.

Few studies have investigated the relationship between different ICT applications and employment. The majority of these studies investigate the link between employment and broadband access or use using data at the municipality/county level (Crandall et al. 2007; Kolko 2012; Atasoy 2013). For instance, using county level data for the US for the period 1999-2007, Atasoy (2013) finds that broadband access is significantly positively associated with an increase in the employment rate. Similarly, using county level data for the US for the period 1999-2006 Kolko (2012) finds that broadband expansion is significantly positively associated with local employment growth. Using similar data for the US, Jayakar and Park (2011) conclude that counties with better broadband availability have lower unemployment rates even after controlling for other factors. A drawback of these studies is that broadband access/use is not separated between households and workplaces. In addition, ICT indicators other than broadband use have been not used so far. An exception is the study by Atasoy, Banker and Pavlou (2013) who study the link between employment and a wide range of ICT applications. The authors distinguish between firm-wide applications (ERP, SCM, CRM, purchasing andextranet) and specific dedicated ICT applications (e-banking, webpage, e-government, e-education). They find a positive relationship between ICT use and employment. However, the effects vary by type of ICT application with larger positive impacts for firm-wide ICT applications than for more specific ICT applications. using firm level data for the UK, In contrast, using firm level data for the UK, De Stefano, Kneller, R., Timmis (2014)do not find any effect of broadband on employment growth.

The other main focus of the study is the link between labour productivity and ICT activities. There are several empirical studies investigating the impact of ICT (for surveys of the literature, see Van Reenen et al. 2010; Biagi, 2013; Cardona, Kretschmer and Strobel 2013). The literature agrees that ICT is a very important driver of productivity (Dahl, Kongsted and Sørensen, 2010; Venturini 2009; O'Mahony and Vecchi, 2005). However, the impact of ICT has been primarily investigated through the impact of ICT capital rather than internet related infrastructure (broadband use, proportion of workers having internet access and mobile internet access). Estimates are provided for two time periods in order to investigate the importance of ICT impact during the economic and financial crises from 2007 onwards. The econometric model is based on a dynamic panel model.

The main contribution of the study is to provide new estimates of the impact of different types of ICT usage, digitalization, and e-commerce activities on labour demand and labour productivity. Few studies have investigated the relationship between these indicators and both employment and labour productivity based on representative and internationally comparable data from several European countries (for an exception, see Pantea et al. 2014).

The chapter is structured as follows: The next section presents the theoretical background and empirical model. The data is then described and the following section offers a range of empirical results. The last section contains concluding remarks.

1.3 Theoretical background and empirical model

ICT infrastructure and usage can have positive or negative effects on employment. The possible impacts on employment are likely to differ considerably by type of ICT and also across industries (e.g. ICT using and producing industries). Investment in ICT infrastructure and increased usage of ICT in the workplace can lead to increases in output due to lower transaction costs and thereby also to the creation of new jobs. This can be referred to as the compensation effect. However, new ICT infrastructures and specific ICT applications such as enterprise resource planning systems can reduce the number of workers for any given output, implying labour saving effects of specific ICT infrastructures due to task obsolescence. This effect is likely to be higher in scale-intensive manufacturing and service industries (Evangelista, 2014). The labour saving effect is also referred to as the displacement effect. A negative employment effect of ICT usage occurs when the magnitude of the displacement effect exceeds that of the compensation effects. This effect is likely to be more pronounced in industries where ICT tends to substitute labour intensive and routine tasks, such as in service sectors characterised by a high share of workers, with routine and repetitive tasks (Evangelista, 2014).

Unlike different types of ICT and internet applications, e-commerce activities directly affect output and material inputs. E-sales activities may replace traditional distribution channels but potentially create new additional sales channels and new markets, thereby increasing employment. E-procurement activities may lead to lower material input costs and thereby increase the productivity level and possibly employment. Given that e-sales activities directly affect the structure of sales and possibly the level of sales, an unconditional labour demand model is specified.

ICT innovations are often accompanied by new ways of organizing work (Edquist, Hommen and McKelvey, 2001). It is generally accepted that changes in business practices, work practices and new human resource management systems lead to increases in productivity by reducing costs and/or improving the quality of existing products (Bresnahan, Brynjolfsson and Hitt, 1999). In particular there is suggestive empirical evidence that certain types of human resource management practices, such as changes in work organization, raise a firm's productivity (Bloom and Van Reenen, 2011). Often these increases in productivity do take place at the expense of employment.

The empirical model can be derived from CES cost function with two production factors, namely labour and capital (Hamermesh, 1996). The main assumption is perfect competition in both the goods and factor markets, i.e. exogenous prices for labour. Capital is assumed to be quasi fixed. The optimal labour demand equation can be derived from the first order condition:

$$L = v^{a} B^{1-\sigma} Y^{(1-\sigma+\sigma v)} \alpha W P^{-\sigma} \quad [1]$$

where v , σ and α are parameters, L denotes employment, Y the valued added in constant prices, WP the real wage rate and B the level of technology. We assume that the production technology is characterised by neutral technological change with rate λ where $B = B_o e^{-\lambda t}$. Following Van Reenen (1997) we assume that output can be approximated by capital and the user cost of capital.[3] Taking logs on both sides of the labour demand equation and adding an error term gives a log-linear static labour demand function where employment is a function of real wages, real output, capital in constant prices and technological change:

$$\ln L_{icst} = \beta_{ics} + \beta_1 Y_{icst} + \beta_2 \ln WP_{icst} + \beta_3 \lambda + \varepsilon_{icst} \quad [2]$$

where *i, c, s* and *t* denote the industry, country, size class and year, respectively. *L* denotes employment, *Y* real output, *WP* real wages, *K* real capital stock and τ the rate of technological change. Further β_{ics} is the fixed (group) effect and ε is the error term with mean zero and assumed i.i..d. The rate of technological change can not be observed directly. We assume that technological change can be captured by the introduction of different types of ICT capacities (Van Reenen 1997). Taking the long difference specification and adding a set of dummy variables leads to the following short-run labour demand function:

$$\Delta \ln L_{icst} = \alpha_0 + \beta_2 \ln \Delta WP_{icst} + \beta_1 \Delta \ln K_{icst} + \Delta ICT_{icst}\theta + \kappa DC + \delta DEC + \mu DSIZE + \vartheta DYR + u_{icst}$$

where $\Delta \ln X_i = (\ln X_i - \ln X_{i,t-2})$ for *X=L, K* and *WP*. [3]

[3] User cost of capital consists of the real price of capital goods, the depreciation rate, and the expected real interest rate. Detailed information on price of capital goods across industries and countries are not available in the ESSlait data. Therefore, we assume that the effects of user cost of capital can be approximated by time and industry/country effects.

The new error term is defined as follows: $u_{icst} \equiv \varepsilon_{icst} - \varepsilon_{icst-2}$, with zero mean and constant variance. Δ refers to the average annual change of the variables between two year periods (2002-2004, 2004-2006, 2006-2008).[4] The variables are defined as follows:

- $\Delta \ln L$ (t): change in log employment,
- $\Delta \ln K$ (t):change in log of real capital stock,
- $\Delta \ln WP$ (t): change in log of the total wage costs per employee deflated by a industry specific value added deflator,
- ICT: vector of various ICT/e-commerce indicators measured as absolute change over a two year period indicators including:
  - Change in % of firms with e-sales
  - Change in % of firms having broadband internet
  - Change in % of firms having a website
  - Change in % of firms with mobile internet access
  - Change in % of firms with e-commerce
  - Change in % of firms with ERP
  - Change in % of firms with orders through internet
  - Change in sales share through computer networks
  - DC, DSEC, DSIZE and DYR are country, sector, size and time dummies.

The employment growth equation can be estimated by OLS with heteroscedasticity consistent standard errors. Since OLS estimates based on cross-sectional data are likely to be sensitive to influential observations, the employment equation is estimated by the robust regression method. This regression technique is a weighted least-squares procedure that puts less weight on outliers. This is achieved by using Cook's distance and then performing Huber iterations. In order to allow for differences in the relationships, the employment equation is estimated separately for broad industry groups and for the subgroup of small and medium-sized enterprises as well as for large firms. A disadvantage of the estimation model in first differences is that it does not allow for the drawing of conclusions about the long-run relationship between ICT and employment.

In general, it is assumed that the direction of causality is going from ICT capacities/e-commerce practices to employment growth. However, e-commerce is most likely endogenous due to output change as well as unobservable factors affecting both output and e-commerce activities at the same time. The system GMM panel data estimator (Blundell and Bond, 1998) can be used to account for the correlation of ICT capacities and e-commerce activities with the error term. 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 with an unbalanced multi-country, industry and size class panel data set over about eight years. Another advantage of the dynamic panel data model is that it provides long run elasticities.

It is likely that different ICT capacities affect employment growth only with a time lag. The literature finds that process innovations take some time to show their impacts (Lachenmaier and Rottmann, 2011). The resulting labour demand model in dynamic form can be written as follows:

$$\ln(L_{icst}) = \alpha_1 \ln(L_{icst-1}) + \alpha_2 \ln(WP_{icst}) + \alpha_3 \ln(K_{icst}) + ICT_{icst}\theta_1 + ICT_{icst-1}\theta_2 + \mu_{ics} + \lambda_t + u_{icst} \quad [4]$$

where μ_{ics} and λ_t denote fixed effects (country-industry-size class pairs) and time effects, respectively. The long-run effect of the ICT indicator on employment growth is obtained by $(\hat{\theta}_1 + \hat{\theta}_1)/(1-\hat{\alpha}_1)$. The regression equation is derived by taking first differences in order to remove the unobserved time-invariant effects (for the sake of convenience, Xs comprising WP and K are suppressed):

[4] Two-year differences of the variables are used rather than annual growth rates to smooth over any year-to-year fluctuations.

$$\ln(L_{icst}) - \ln(L_{icst-1}) = \tilde{\alpha}(\ln(L_{icst-1}) - \ln(L_{icst-2})) + \tilde{\beta}_1'(ICT_{icst} - ICT_{icst-1})$$
$$+ \tilde{\beta}_2'(\ln(ICT_{it-1}) - \ln(ICT_{it-2})) + \lambda_t + (\varepsilon_{it} - \varepsilon_{it-1}) \quad [5]$$

Assuming that the residuals of the level equation are serially uncorrelated, the values of *Y* lagging two periods or more can be used as instruments in the first-differenced equation. We use the system GMM estimator introduced by Blundell and Bond (1998) to estimate the labour demand model. The system GMM estimator builds on two equations: the first is based on the first difference specification and the other on the equation in levels. Variables in the equation in levels are instrumented with lags of their own first differences. As a rule-of-thumb the number of instruments should not exceed the number of groups in the regression. The two-step estimator is used to estimate the labour productivity equation with the finite sample correction developed by Windmeijer (2005). The ICT indicators are treated as endogenous (predetermined).

In addition to the labour demand equation the labour productivity equation will be estimated. The labour productivity equation in dynamic form can be written as follows:

$$\ln(Y_{icst} / L_{icst}) = \alpha_1 \ln(Y_{icst} / L_{icst-1}) + ICT_{icst}\theta_1 + ICT_{icst-1}\theta_2 + \mu_{ics} + \lambda_t + u_{icst} \quad [6]$$

where μ_{ic} and λ_t denote fixed effects (country-industry pairs) and time effects, respectively. Since ICT needs time to show significant returns, both the current and lagged ICT indicators are used. The long run effect of e-sales activities on labour productivity is obtained by $(\hat{\theta}_1 + \hat{\theta}_2)/(1 - \hat{\alpha}_1)$.

1.4 Data and descriptive statistics

The data is based on the meso-aggregated Micro Moments Database. This database holds linked and micro-aggregated information on firms drawn from the national statistical offices in 14 European countries (Austria, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Sweden, Slovenia and the United Kingdom). For these European countries firm-level information from the business register (BR), the production survey (PS), the ICT usage (EC) survey and the Community Innovation (CIS) survey has been harmonised and then merged. This dataset has been built up by the aid of the Distributed Microdata Approach (Bartelsman, 2004).

The data is available at the two-digit industry level as well as for the EUKLEMS alternative hierarchy (see Table 12 in appendix for industry classifications). The dataset is also available in several other dimensions:

- Size class (10-19, 20-49, 50-249 and 250+)
- Age (<5 years, >5=years) and size (<50, >50)
- High growth firms
- Share of broadband connected employees in four categories
- Innovation activity
- Foreign ownership, multinational firms and exporting activities

The industry classification is based on NACE rev 1.1 (5-37 and 50-99, exclusive of energy, water and construction -industries 40-45- and contains information for the period 2000-2010). Note that industries 75 to 99 are partially covered. All series are adjusted for the change in industry classification from NACE rev 1.1 to NACE rev 2 starting from 2008 onwards. In particular, a concordance file based on a possible overlap of two industry classifications in a single year is used to change industry codes at the Nace rev 2 level to Nace 1.1 codes at the firm level from 2008 onwards (Bartelsman et al., 2013).

In this study the analysis is based on two estimation samples: (i) one including information at the two-digit industry level and (ii) the second including broad industry classes based on the EUKLEMS definition cross classified by size class. The industry/size class panel contains information for six broad industry classes for each of the four firm size classes (10-19, 20-49.50-249, 250+). These industry groups can be classified into

ICT using and ICT producing industries. ICT using manufacturing industries include (i) Consumer manufacturing, (ii) Intermediate manufacturing and (iii) Investment goods, excluding high-tech industries. ICT producing industries include electrical machinery, post and communication services. ICT using service industries include (i) distribution and (ii) financial and business services except real estate (see table 12 in the Appendix for a classification of the industries).

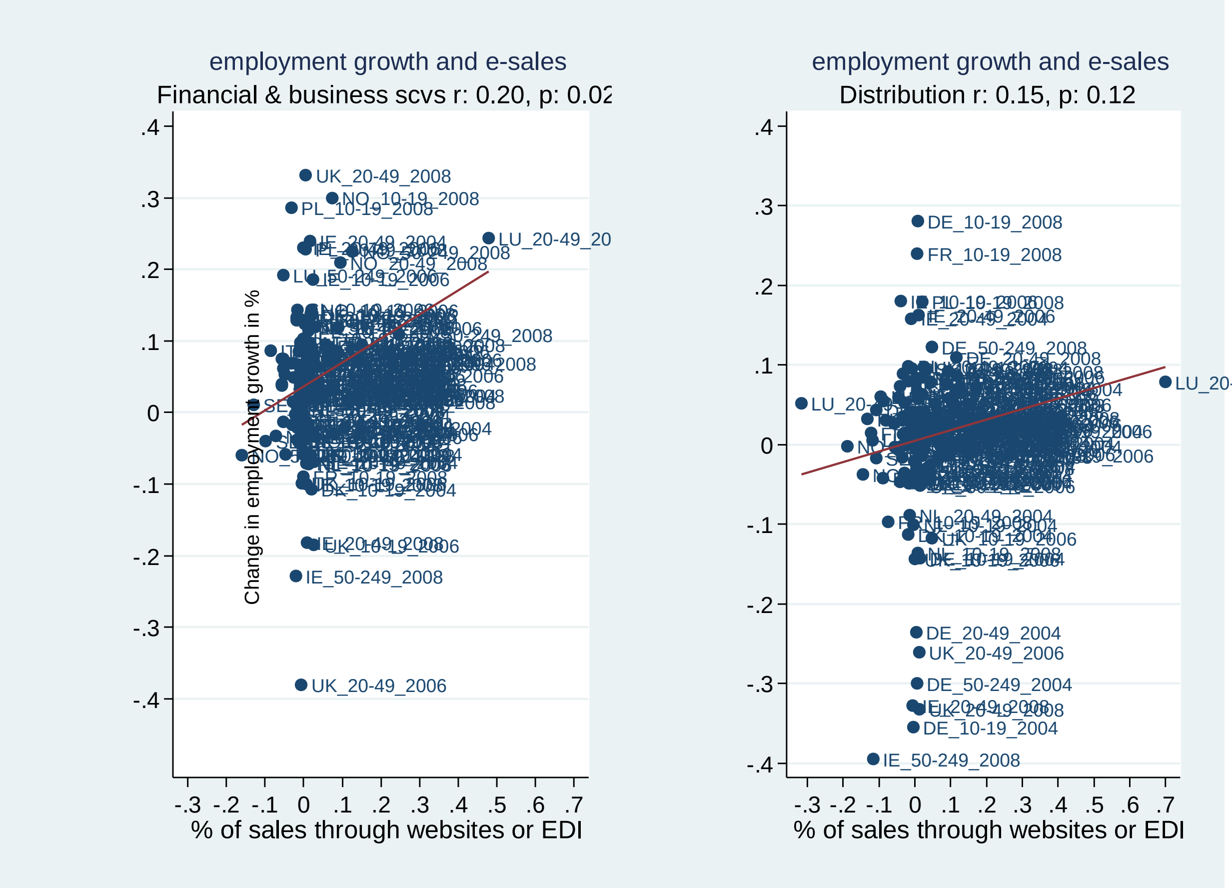
Variables available may vary somewhat across countries, partly following the feasibility to link datasets (legal as well as practical), partly depending on the model design of sample surveys, where certain questions are mandatory and others are not. Nominal prices have been deflated by EUKLEMS or WIOD two-digit price indexes. The ICT variables give the percentage of firms in an industry using the tool in question, unless something else is explained. Size of firm is represented by the number of employees.

This study uses aggregated data to study the impacts of ICT. In principle, it is possible to investigate the employment effects of ICT at the firm level (Pantea et al., 2014). However, linking several waves of the ICT/e-commerce survey over time lead to high rates of sample attrition. This is due to the rotating design of the ICT/e-commerce survey. In this case the same firms rarely overlap across several different waves and thus panel data methods at the firm level would offer little additional insights.

In order to get a first idea of the pattern of association between employment growth and ICT/e-commerce activities, selected scatter plots are presented. Figure 1 plots the change in employment growth against the change in the share of e-sales to total sales for two service industries, namely distribution and financial and business services for four given size classes (i.e. 10-19, 20-49, 50-249, 250+). The sample is restricted to the period before the financial and economic crisis of 2002-2008 and changes are measured over a two-year interval. The reason for this is that employment growth during the 2008/2010 is strongly influenced by the fall in demand rather than by ICT infrastructure or structural characteristics.

As can be seen in Figure 1, in business services, employment growth and increase in e-sales activities go hand in hand with a correlation coefficient of 0.20 and a marginal significance level of 2%. However, for distribution the correlation is positive but not significant at the 10% level. For remaining industries, namely manufacturing industries and ICT using industries, we do not find significant correlations. This also holds true for the remaining ICT indicators. The correlations should be interpreted with caution because they suffer from omitted variable bias since country, time and industry effects are not accounted for. Nevertheless, they could give a first indication of a possible positive relationship. Figure 3 in the Appendix shows the corresponding scatter plot between the change in labour productivity and broadband internet use. While there is a significant relationship between labour productivity growth and broadband internet use in manufacturing industries, there is no significant relationship in service industries.

Figure 1: Relationship between employment growth and change in the share of e-sales due to websites



Source: ESSLait Micro Moments Database.

1.5 Empirical results for the labour demand model

Table 1.1 shows robust regression estimates of the relationship between different types of ICT usage and e-commerce activities on the annual growth rate of employment for the period 2002-2008 where variables are calculated as changes over two year intervals. Separate results for SMEs and for large firms (defined as 250 employees and more) are provided. Table 2 shows the corresponding results for the ICT using manufacturing industries, ICT using service industries, and ICT producing industries. All regressions include country, industry and size class dummy variables. The main result is that changes in the different types of ICT/e-commerce activities measured as changes over a two year period are not significantly related to employment growth when controlling for the impact of change in real wages and capital stock. The insignificant effects also hold true for more advanced ICT applications and e-commerce activities. The results are in line with Pantea et al. (2014) based on firm level data for seven EU countries. However, the results stand in contrast to the predictions of Brynjolfsson and McAfee (2011) suggesting that ICT activities lead to replacement of labour by ICT enabled equipment.

Table 1: Impact of ICT and e-commerce activities on employment growth for SMEs and large firms (robust regression estimates based on the multi-industry size class panel)

	total			SMEs			large firms		
	coeff.		t	coeff.		t	coeff.		t
change in % of firms with e-sales	0.00		-0.47	-0.01		-1.08	0.01		0.75
change in log real wages	-0.09	***	-3.51	-0.02		-0.83	-0.17	***	-2.61
change in log real capital stock	0.01	***	3.43	0.04	***	8.26	0.01	**	2.22
constant	-0.05	***	-3.87	0.01		1.20	0.09		1.50
number of observations	728			544			184		
	coeff.		t	coeff.		t	coeff.		t
change in % of firms broadband internet	0.02		1.07	0.02		0.84	0.02		0.51
change in log real wages	-0.10	***	-4.13	-0.09	***	-3.45	-0.13	**	-2.13
change in log real capital stock	0.01	***	4.17	0.04	***	7.67	0.01	***	3.00
constant	-0.02	*	-1.76	0.01		0.66	0.02		0.93
number of observations	852			637			215		
	coeff.		t	coeff.		t	coeff.		t
change in % of firms having a website	0.01		0.58	0.00		0.29	0.03		1.47
change in log real wages	-0.09	***	-3.45	-0.02		-0.62	-0.17	***	-2.78
change in log real capital stock	0.01	***	3.35	0.04	***	7.77	0.01	**	2.48
constant	-0.03	**	-2.15	-0.03	**	-2.02	-0.06		-2.80
number of observations	704			526			178		
	coeff.		t	coeff.		t	coeff.		t
change in % of firms with mobile internet access	0.00		0.36	-0.01		-0.66	0.02		1.56
change in log real wages	-0.19	***	-6.89	-0.18	***	-5.96	-0.22	***	-3.00
change in log real capital stock	0.05	***	9.02	0.05	***	9.21	0.05	*	2.02
constant	0.00		-0.25	-0.01		-0.57	-0.05		-2.20
number of observations	542			404			138		
	coeff.		t	coeff.		t	coeff.		t
change in % of firms with e-commerce	0.02		1.33	0.02		1.23	0.00		0.08
change in log real wages	-0.11	***	-3.99	-0.07	**	-2.28	-0.13	*	-1.91
change in log real capital stock	0.01	***	3.92	0.04	***	7.94	0.01	*	1.95
constant	-0.02		-1.54	-0.03		-1.79	0.05		1.01
number of observations	739			554			185		
	coeff.		t	coeff.		t	coeff.		t
change in % of firms with ERP	0.01		1.03	-0.01		-0.80	0.00		0.23
change in log real wages	-0.25	***	-5.91	-0.52	***	-11.06	-0.50	**	-4.09
change in log real capital stock	0.04	***	4.49	0.04	***	4.72	0.03		1.17
constant	-0.01		-1.11	0.21	***	14.7	0.02		1.17
number of observations	153			117			39		
	coeff.		t	coeff.		t	coeff.		t
change in % of orders through internet	-0.02		-0.40	0.01		0.15	-0.10		-1.27
change in log real wages	-0.11	***	-4.06	-0.07	**	-2.30	-0.12	*	-1.73
change in log real capital stock	0.01	***	3.86	0.05	***	8.05	0.01	**	2.13
constant	-0.02	*	-1.66	0.04	***	2.67	-0.07		-2.72
number of observations	741			556			185		
	coeff.		t	coeff.		t	coeff.		t
change in sales share through computer networks	0.02		1.18	0.01		0.45	0.02		0.66
change in log real wages	-0.11	***	-4.01	-0.07	**	-2.24	-0.12	*	-1.86
change in log real capital stock	0.01	***	3.88	0.04	***	8.21	0.01	**	2.13
constant	-0.06	***	-4.46	0.00		-0.09	-0.06		-2.49
number of observations	774			578			196		

Note: The dependent variable is the change in log employment over two year intervals (2002-2004, 2004-2006, 2006-2008). All regressions include country, industry and size class dummy variables (the latter are not included in the sample of large firms). ***, ** and * denote significance at the 1, 5 and 10% levels. Source: ESSLait Micro Moments Database.

Wage growth and growth of capital stock shows the expected signs and are significant at the 5% level in the majority of cases. However, the size of the wage and capital effects is rather small. The short run wage elasticity is about -0.10 and the capital stock elasticity is about 0.01. The low elasticities in absolute terms are related to the estimation method of long differences. Several robustness checks have been conducted. First, ICT indicators lagged two years are used instead of contemporaneous ICT indicators. Unreported results confirm that the ICT indicators are not significant at the conventional significance levels. Second, lagged levels of the ICT indicators are used instead of their changes. Again, lagged levels of the ICT indicators are not significant.

When we use the sample that distinguishes between ICT producing and ICT using industries, the results again show that the different types of ICT/e-commerce indicators are not significantly related to employment growth (Table 2). An exception is e-sales activity for service industries where we find a positive and significant relationship with employment growth. However, the coefficient is only significant at the 10% level. The coefficient of 0.08 means that an increase in the ratio of e-sales to total sales by one percentage point (say from 8 to 9%) is associated with an increase is in the employment growth rate of almost 0.1 percentage point per year. The magnitude of this relationship is quite small given the average annual growth of employment of about 1.5% in financial and business services for the 14 European countries for the period 2002-2008.

The next step is to investigate the employment effects of ICT using dynamic panel data methods. Table 3 shows the impact of two selected ICT indicators on the long-run labour demand estimated by the two-step system GMM estimator for the sample of manufacturing and service industries.[5] Estimates are provided for two subsamples, namely for the pre financial and economic crises, and for the total sample period 2002-2010.

Table 2: Impact of ICT and e-commerce activities on employment growth for ICT producing and using industries (robust regression estimates based on the multi-industry size class panel)

	manufacturing ICT using			services ICT using			ICT producing		
	coeff.		t	coeff.		t	coeff.		t
change in % of firms with e-sales	-0.01		-1.08	0.01		0.64	0.02		0.62
change in log real wages	0.08		1.31	-0.29	***	-4.47	-0.19	***	-3.63
change in log real capital stock	0.01	**	2.41	0.01	*	1.97	0.08	***	4.94
constant	0.02		1.60	0.03		2.14	0.03		0.58
number of observations	374			234			117		
	coeff.		t	coeff.		t	coeff.		t
change in % of firms broadband internet	0.01		0.67	-0.01		-0.18	0.08		1.50
change in log real wages	-0.02		-0.52	-0.26	***	-4.48	-0.12	**	-2.58
change in log real capital stock	0.02	***	3.13	0.01	**	2.53	0.01	*	1.71
constant	-0.01		-0.88	-0.03		-2.17	-0.02		-0.47
number of observations	438			274			138		
	coeff.		t	coeff.		t	coeff.		t
change in % of firms having a website	0.00		0.33	0.01		0.45	0.03		0.81
change in log real wages	0.07		1.17	-0.31	***	-4.64	-0.20	***	-3.91
change in log real capital stock	0.01	**	2.36	0.01	*	1.89	0.08	***	5.21
constant	-0.04	**	-2.51	-0.07		-3.83	0.02		0.54
number of observations	362			226			113		
	coeff.		t	coeff.		t	coeff.		t
change in % of firms with mobile internet access	0.00		0.02	-0.01		-0.94	0.01		0.26
change in log real wages	0.14	*	1.78	-0.34	***	-4.88	-0.32	***	-6.28
change in log real capital stock	0.17	***	20.72	0.03	***	3.53	0.07	***	4.82
constant	0.02		0.77	-0.05		-1.75	0.01		0.22
number of observations	279			177			86		
	coeff.		t	coeff.		t	coeff.		t
change in % of firms with e-commerce	0.01		0.39	0.04		1.49	0.03		0.86
change in log real wages	0.03		0.45	-0.29	***	-4.17	-0.18	***	-3.61
change in log real capital stock	0.02	***	2.79	0.01	**	2.29	0.06	***	3.94
constant	0.02		1.38	0.02		0.93	-0.06		-1.62
number of observations	380			233			123		
	coeff.		t	coeff.		t	coeff.		t
change in % of firms with ERP	0.01		0.97	-0.02		-1.02	-0.02		-0.43
change in log real wages	0.30	**	2.32	-1.06	***	-11.5	-0.60		-1.22
change in log real capital stock	0.16	***	10.19	0.06	***	3.76	0.04		1.16
constant	-0.01		-0.69	0.03		2.28	-0.01		-0.10
number of observations	80			48			23		
	coeff.		t	coeff.		t	coeff.		t
change in % of orders through internet	-0.06		-0.80	0.00		-0.07	0.02		0.19
change in log real wages	0.03		0.48	-0.33	***	-4.58	-0.18	***	-3.50
change in log real capital stock	0.02	***	2.77	0.01	**	2.13	0.06	***	4.16
constant	0.02		1.35	0.02		0.86	-0.02		-0.26
number of observations	381			233			124		
	coeff.		t	coeff.		t	coeff.		t
change in sales share through computer networks	0.00		0.24	0.08	*	1.85	0.03		0.51
change in log real wages	0.02		0.44	-0.28	***	-4.31	-0.17	***	-3.34

[5] The GMM estimations are carried out using the XTABOND2 (updated 2014 July 27th) command in STATA 13 (see Roodman, 2009).

	manufacturing ICT using			services ICT using			ICT producing		
change in log real capital stock	0.02	***	2.79	0.01	**	2.43	0.05	***	3.52
constant	0.03		1.85	0.03		1.79	0.00		-0.11
number of observations	379			250			124		

Note: The dependent variable is the change in log employment over two year intervals (2002-2004, 2004-2006, 2006-2008). ***, ** and * denote significance at the 1, 5 and 10% levels. Source: ESSLait Micro Moments Database.

Furthermore, specifications with e-sales and broadband connected employees lagged one year are provided. The GMM regressions use robust standard errors and treat all explanatory variables as predetermined. The Hansen J-test supports the validity of the instruments in about half of the cases. For manufacturing for the period 2002-2007 we find a statistically significant positive relation between e-sales activities and employment. This indicates that industries/size classes with an increase in the number of firms with e-sales activities exhibit higher employment growth. This result stands in contrast to the specifications in first differences. However, in general GMM panel data estimates are preferable to cross-sectional estimates because the use of lagged variables reduces a possible bias due to measurement errors. The short-run coefficient is 0.46 indicating that an increase in percentage of firms with e-sales activities of one percentage point is associated with an increase in employment by 0.46%. For the total period we find that the e-sales variables become insignificant. This is not surprising given that job losses during the economic and financial crises are rather caused by an external shock than by changes in e-sales activities. In contrast, broadband connected employees do not appear to have a significant effect on employment. For services there is also some evidence that e-sales activities have a positive impact on employment. However, the coefficient is only significant at the 10% level. Overall no negative employment effects of ICT and e-sales activities can be found. If anything there is some evidence for positive effects of e-sales activities. The coefficients on the remaining ICT indicators are not significantly different from zero (results are available upon request)

Table 3: Impact of change in different ICT indicators on employment (System GMM estimates)

	manufacturing											
	coeff.		t	coeff.		t	coeff.		t	coeff.		t
	2002-2007			2002-2010			2002-2007			2002-2010		
log employment t-1	0.947	***	16.24	0.994	***	14.97	0.938	***	35.44	0.936	***	30.47
% firms w e-sales t	0.462	***	3.65				0.155		0.96			
% firms w e-sales t-1				0.029		0.82				0.057		1.36
log real wages t	-0.409	***	-3.74	-0.174	*	-1.67	-0.286	**	-2.14	-0.181	**	-2.27
log real capital stock t	0.037		1.46	0.079	***	2.39	-0.002		-0.10	0.006		0.42
time dummies	yes			yes			yes			yes		
constant	1.411		1.60	-0.405		-0.50	1.644		3.54	1.225	***	2.88
# of observations	682			1057			659			1033		
# of groups	130			130			130			130		
Hansen test (p-value)	0.641			0.084			0.030			0.046		
log employment t-1	0.928	***	18.20	0.976	***	25.30	0.928	***	24.74	0.933	***	30.21
% broadband internet t	0.347		1.33				-0.100		-0.70			
% broadband internet t-1				0.223		1.63				0.109		0.98
log real wages t	-0.315	***	-2.91	-0.148	*	-1.70	-0.186		-1.65	-0.213	**	-2.59
log real capital stock t	0.079	***	2.76	0.069	**	2.13	-0.003		-0.10	0.012		0.60
time dummies	yes			yes			yes			yes		
constant	0.734		0.86	-0.224		-0.35	1.483		2.57	1.264	***	3.12
# of observations				671			1060			1045		
# of groups	130			130			130			130		
Hansen test (p-value)	0.024			0.089			0.011			0.002		

	manufacturing											
	coeff.		t	coeff.		t	coeff.		t	coeff.		t
	2002-2007			2002-2010			2002-2007			2002-2010		
	services											
	2002-2007			2002-2010								
log employment t-1	1.03	***	22.32	0.88	***	12.02						
share of e-sales value t	0.14		0.81									
share of e-sales value t-1				0.61	*	1.73						
log real wages t	-0.01		-0.19	-0.35	**	-2.16						
log real capital stock t	0.03		1.29	0.02		0.67						
time dummies												
constant	-0.70		-0.90	2.38		1.98						
# of observations	424			654								
# of groups	80			80								
Hansen test (p-value)	0.20			0.08								

Note . : ***, ** and * denote significance at the 1, 5 and 10% levels. The table reports two-step GMM results with the Windmeijer correction for small samples. The ICT and the wage variables are treated as predetermined (endogenous). The Hansen J test checks for the validity of instrumental variables. The number of instruments is between 50 and 63.

1.6 Empirical results for the labour productivity

Table 4 shows the system GMM estimates of the labour productivity equation for the total sample, and for manufacturing and service industries, respectively. Here the sample is based on two-digit industry level data instead of broad industry groups by size classes used for the employment equation. The table contains the coefficients and the long-run elasticities. The Hansen test of exogeneity of the instruments could not reject the null hypothesis of exogenous instruments in the GMM system estimates at the 5% level in most of the cases. Similarly, unreported results show that the tests of serial correlation reject the hypothesis that the error term exhibits second-order serial correlation.

For the total sample we find that the different types of ICT indicators (lagged one year) have a significant impact on labour productivity. In particular, broadband connected employees, and the presence of website and mobile internet access are all highly significant at the 5% level. However, enterprise resource planning systems are not significant at conventional significance levels. A possible explanation is that ERP systems are often accompanied by a reorganisation of the firm and other organisational changes which can take time to show an impact on output.

Overall the results indicate a positive and significant association between different ICT indicators and labour productivity. For instance, the long-run elasticity of the share of broadband connected employees with respect to real labour productivity is 0.94. This indicates that an increase in the share of broadband connected employees by one percentage point leads to an increase in labour productivity by almost 1%. The magnitude of the effects is similar for the percentage of firms having a website and mobile internet access. When distinguishing between manufacturing and services industries we find significant differences in the impact of the different ICT capacities. For manufacturing we again find that the different ICT indicators are all significant at the 5% level, with the exception of enterprise resource planning systems. In contrast, for firms in services, only the percentage of mobile internet users matters, whereas the remaining ICT indicators are not significant at the 5% level. The significance of mobile internet usage for service firms is an interesting and new finding in the literature. A possible explanation is that, unlike in manufacturing firms, in service firms there is a high need for frequent face-to-face contact with clients. It is notable that mobile internet usage is significant even when time effects are controlled for.

Table 4: Impact of change in ICT on labour productivity 2003-2010 (System GMM estimates)

	Total			Manufacturing industries			Service industries		
	coeff.		t	coeff.		t	coeff.		t
log labour productivity t-1	0.74	***	12.07	0.80	***	11.89	0.56	***	5.15
% of firms with broadband internet t-1	0.24	**	2.36	0.25	***	2.82	-0.10		-0.50
long-run coeff. % firms w. broadband internet t-1	0.94	**		1.24	***		-0.24		
number of observations	2278			1503			775		
number of industry country group pairs	317			208			109		
number of instruments	151			151			151		
Hansen test (p-value)	0.02			0.12			0.99		
diff-in-Hansen tests excl. groups (p-value)	0.01			0.20			0.89		
	coeff.		t	coeff.		t	coeff.		t
log labour productivity t-1	0.76	***	12.48	0.81	***	12.75	0.63	***	6.39
% of firms having a website t-1	0.23	**	2.33	0.26	***	3.10	-0.01		-0.03
long-run coeff. % of firms having a website t-1	0.96	**		1.37	***		-0.02		
number of observations	2209			1458			751		
number of industry country group pairs	317			208			109		
number of instruments	160			160			160		
Hansen test (p-value)	0.02			0.14			1.00		
diff-in-Hansen tests excl. groups (p-value)	0.01			0.19			0.99		
	coeff.		t	coeff.		t	coeff.		t
log labour productivity t-1	0.74	***	11.10	0.83	***	12.05	0.66	***	6.98
% of firms having mobile internet access t-1	0.16	*	1.74	0.07		1.11	0.31	**	2.27
long-run coeff. % firms having mobile internet t-1	0.64	*		0.43			0.89	**	
number of observations	2095			1383			712		
number of industry country group pairs	317			208			109		
number of instruments	152			152			152		
Hansen test (p-value)	0.00			0.08			1.00		
diff-in-Hansen tests excl. groups (p-value)	0.00			0.05			0.92		
	coeff.		t	coeff.		t	coeff.		t
log labour productivity t-1	0.70	***	6.79	0.77	***	7.45	0.49	***	3.29
% of firms having ERP t-1	0.00		0.03	-0.04		-0.44	-0.04		-0.16
long-run coeff. % of firms having ERP t-1	0.01			-0.18			-0.07		
number of observations	1157			761			396		
number of industry country group pairs	317			208			109		
number of instruments	85			85			85		
Hansen test (p-value)	0.003			0.087			0.723		
Diff-in-Hansen tests excl. groups (p-value)	0.112			0.092			0.49		
	coeff.		t	coeff.		t	coeff.		t
log labour productivity t-1	0.74	***	11.78	0.81	***	12.15	0.56	***	5.01
% of workers with internet access t-1	0.24		1.52	0.22	**	2.42	-0.02		-0.10
long-run coeff. % of workers with internet access	0.92			1.11	**		-0.05		
number of observations	2278			1503			775		
number of industry country group pairs	317			208			109		
number of instruments	160			160			80		
Hansen test (p-value)	0.01			0.16			1.00		
Diff-in-Hansen tests excl. groups (p-value)	0.01			0.14			0.99		
	coeff.		t	coeff.		t	coeff.		t
log labour productivity t-1	0.73	***	10.30	0.79	***	10.36	0.60	***	5.75
% of workers with mobile internet access t-1	0.32	***	3.37	0.37	***	3.24	0.29	**	2.17
long-run coeff. % workers with mobile internet	1.17	***		1.73	***		0.73	**	
number of observations	2072			1368			704		
number of industry country group pairs	317			208			109		
number of instruments	144			144			80		
Hansen test (p-value)	0.00			0.04			0.08		
Diff-in-Hansen tests excl. groups (p-value)	0.00			0.09			0.99		

Notes: *,** and *** are statistically significant at the 10, 5 and 1% level, respectively. The table provides the results of the two-step system GMM estimator where the t-values are based on the small sample correction of the variance estimates proposed by Windmeijer (2005) and are robust to heteroscedasticity. The ICT variables are treated as predetermined and instrumented with its lagged values (from the first to the fifth lag).

As a robustness check we also provide estimation results for the more recent period 2007-2010. Dimelis and Papaioannou (2011) suggest that the returns to ICT differ across time. Estimation for different time periods makes it possible to investigate whether the

ICT returns are diminishing when reaching the saturation levels. Table 5 shows that the size and significance of the different ICT indicators decreased for the period 2007-2010 in most of the cases as compared to the total sample. This particularly holds true for broadband internet usage which is no longer significant for manufacturing industries. In contrast, for service industries, mobile internet access increases in importance for the more recent period with a long-run coefficient of 1.06 as compared to 0.73 for the total sample. However, it is important to note that the change in the coefficients might be also caused by the financial and economic crisis.

Table 5: Impact of change in ICT on labour productivity 2007-2010 (System GMM estimates)

	Total			Manufacturing industries			Service industries		
	coeff.		t	coeff.		t	coeff.		t
log labour productivity t-1	0.65	***	7.71	0.74	***	6.83	0.39	***	3.85
% of firms with broadband internet t-1	0.14		0.82	0.10		0.67	0.14		0.44
long-run coeff. % firms w. broadband internet t-1	0.40			0.37			0.23		
number of observations	1207			795			412		
number of industry country group pairs	317			208			109		
number of instruments	91			91			91		
Hansen test (p-value)	0.00			0.00			0.46		
Diff-in-Hansen tests excl. groups (p-value)	0.01			0.00			0.52		
	coeff.		t	coeff.		t	coeff.		t
log labour productivity t-1	0.65	***	6.93	0.73	***	7.14	0.44	***	3.68
% of firms having a website t-1	0.26	**	2.22	0.34	***	3.01	0.05		0.10
long-run coeff. of firms having a website t-1	0.75			1.24			0.09		
number of observations	1209			797			412		
number of industry country group pairs	317			208			109		
number of instruments	91			96			96		
Hansen test (p-value)	0.01			0.58			0.37		
Diff-in-Hansen tests excl. groups (p-value)	0.01			0.01			0.44		
	coeff.		t	coeff.		t	coeff.		t
log labour productivity t-1	0.67	***	7.56	0.77	***	8.09	0.43	***	3.04
% of firms having mobile internet access t-1	0.12		0.87	-0.02		-0.16	0.83	***	2.60
long-run co. % firms having mobile internet t-1	0.36			-0.08			1.45		
number of observations	1186			782			404		
number of industry country group pairs	317			208			109		
number of instruments	92			92			92		
Hansen test (p-value)	0.00			0.00			0.37		
diff-in-Hansen tests excl. groups (p-value)	0.00			0.01			0.29		
	coeff.		t	coeff.		t	coeff.		t
log labour productivity t-1	0.75	***	6.96	0.76	***	7.04	0.44	**	2.46
% of firms having ERP t-1	0.05		0.33	-0.02		-0.22	-0.05		-0.18
long-run coeff. % of firms having ERP t-1	0.20			-0.08			-0.09		
number of observations	1094			722			372		
number of industry country group pairs	317			208			109		
number of instruments	88			88			72		
Hansen test (p-value)	0.00			0.01			0.31		
Diff-in-Hansen tests excl. groups (p-value)	0.00			0.02			0.23		
	coeff.		t	coeff.		t	coeff.		t
log labour productivity t-1	0.63	***	7.06	0.74	***	6.87	0.40	***	4.23
% of workers with internet access t-1	0.12		0.64	0.16		1.07	0.11		0.31
long-run co. % workers with internet access t-1	0.32			0.62			0.18		
number of observations	1207			795			412		
number of industry country group pairs	317			208			109		
number of instruments	96			96			96		
Hansen test (p-value)	0.000			0.002			0.416		
Diff-in-Hansen tests excl. groups (p-value)	0.006			0.001			0.295		
	coeff.		t	coeff.		t	coeff.		t
log labour productivity t-1	0.64	***	6.62	0.74	***	6.96	0.29	**	2.09
% of workers with mobile internet access t-1	0.27	*	1.75	0.32	**	1.99	0.75	***	3.05
long-run co. % of workers w. mobile internet t-1	0.74	*		1.24	**		1.06	***	
number of observations	1184			780			404		
number of industry country group pairs	317			208			109		
number of instruments	88			88			88		
Hansen test (p-value)	0.00			0.00			0.48		
Diff-in-Hansen tests excl. groups (p-value)	0.00			0.00			0.35		

Notes: *, ** and *** are statistically significant at the 10, 5 and 1% level, respectively. The table provides the results of the two-step system GMM estimator where the t-values are based on the small sample correction of the variance estimates proposed by Windmeijer (2005) and are robust to heteroscedasticity. The ICT variables are treated as predetermined and instrumented with its lagged values (from the first to the fifth lag).

1.7 Conclusions

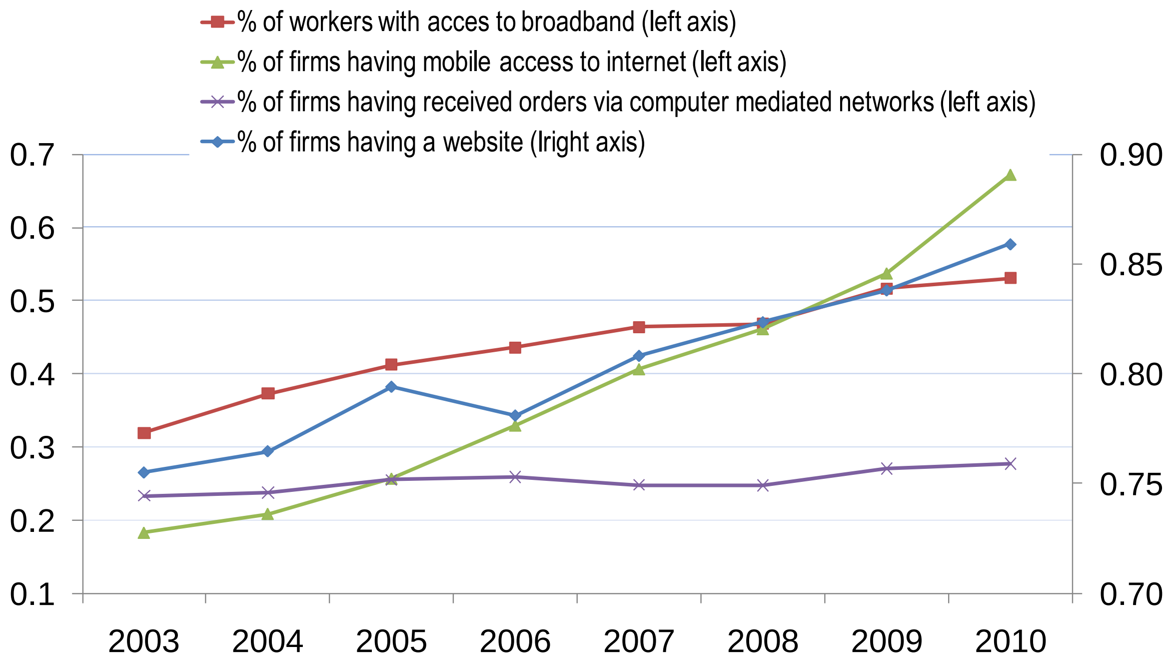
This study presents further insights into the impacts of the different ICT applications and e-commerce activities on employment and productivity using internationally comparable data for 14 European countries. We have estimated static labour demand equations in long differences distinguished by size class and by sector (ICT using and ICT producing) for the period 2002-2010. In addition, dynamic labour demand equations have been estimated. In the absence of access to linked firm-level data sets, the use of micro aggregated data can provide useful results on the impacts of ICT. Representative micro aggregated data by firm size and industry groups suffer less from attrition and sample selection, both of which are caused by the rotating nature of the ICT/e-commerce survey. Data for this analysis originates from the ESSLait Micro Moments Database. This database contains linked and micro-aggregated information on firms sourced from the national statistical offices. Information is available from registers on business, trade and education as well as from surveys on production, ICT usage and innovation activities for the years 2001-2010. A key feature of our analysis is the use of different types of advanced ICT indicators.

The main result is that different types of ICT applications do not reduce employment. For e-sales activities there is some evidence of positive effects. This indicates that ICT technologies are not labour saving but rather neutral to employment. The results are robust not only to the model specification but also the econometric methodology. There are several implications for policy makers. In contrast to the popular view, we do not find that different ICT applications destroy jobs. If anything there are positive effects from e-commerce activities. However, these effects can only be observed for manufacturing firms.

Rather than affecting employment, different types of ICT capacities are significantly related to labour productivity. However, the productivity effect of ICT varies across type of ICT and also between manufacturing and service industries. The share of broadband connected employees and the percentage of workers using the internet are more powerful productivity determinants in services, whereas mobile internet access is more relevant for service industries. There are also significant differences across time. For the most recent period for manufacturing industries the magnitude of the ICT impact decreases while for service industries the relevance of the share of workers with mobile internet access use increases over time. There are several ideas for future work. One idea is to test to what extent complementary factors such as skills are needed to maximise the benefits of ICT.

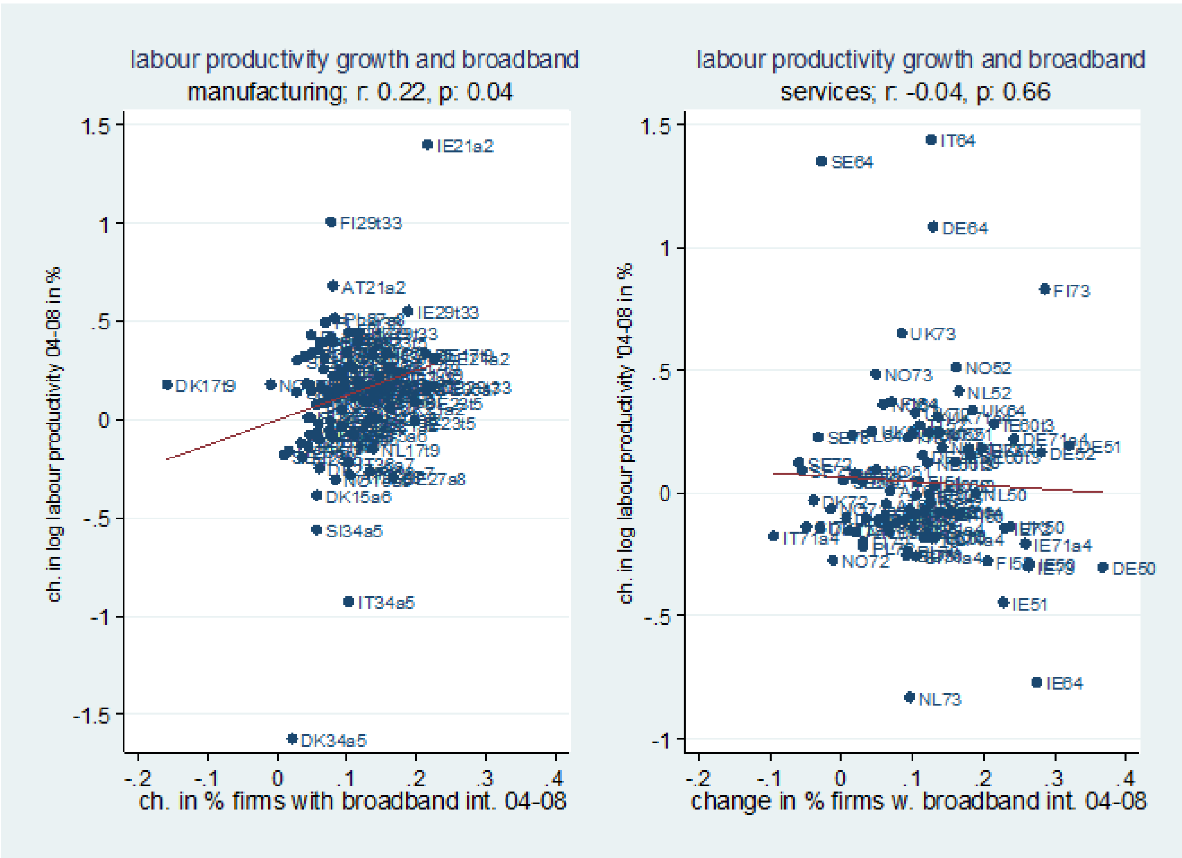
1.8 Appendix

Figure 2: Evolution of different ICT indicators over time



Source: ESSLait Micro Moments Database.

Figure 3: Relationship between productivity growth and change in broadband internet use



Source: ESSLait Micro Moments Database.

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Study 2. Relative demand for highly skilled workers and use of different ICT and internet technologies: New Evidence for Seven European Countries

2.1 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 data for seven European countries for the period 2002-2010. For manufacturing industries, static fixed effects models show that broadband connected employees, diffusion of mobile internet, use of enterprise resource planning systems and electronic invoicing are all significantly positively related to the industries' skill intensity. For service industries only mobile internet usage is significant. Specifically for manufacturing an increase of 10 percentage points in the percentage of firms with ERP systems is associated with an increase in the share of highly skilled workers by 0.5 percentage points over a two year period. These estimates indicate that the increase in ERP systems during the period studied accounts for 25% 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 when accounting for endogeneity of ICT.

Keywords: skill intensity, broadband enabled employees, enterprise resource planning systems, skill-biased technological change

2.2 Introduction

There is an ongoing discussion on the relationship between the skill structure of the workforce and investment in information and communication technologies. Earlier studies have investigated the effect of the relationship between the use of ICT investment or ICT capital and the relative demand for skilled workers, documenting a significant and positive relationship between ICT capital or investment and the share of highly skilled workers (for surveys of the literature, see Vivarelli, 2014; Sabadash, 2013). Such a positive relationship between skills and technology at the expense of unskilled workers is commonly referred to as "skill-biased technological change". For instance, using industry level data for US manufacturing and service industries for the period 1950-1990, Autor, Katz, and Krueger (1998) find a significant positive relationship between investment in computers and the industries' skill intensity. Haskell and Heden (1999) and Green, Felstead and Gallie (2003) find similar evidence for the UK (see also Falk and Seim, 2001, for Germany; Piva and Vivarelli, 2002, for Italy; Bayo-Moriones et al., 2007, for Spain). 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 high skilled and low skilled workers, and reducing the demand for medium skilled workers.[6] This is confirmed by the work of Michaels, Natraj, and Van Reenen (2010), who - using industry level data for the US, Japan, and nine European countries for the period 1980-2004 - find that industries with faster growth of ICT capital exhibit greater increases in relative demand for highly educated workers, while reducing the relative demand for middle educated workers, and having little effect on the demand for unskilled workers (i.e. ICT job polarization).

However, a striking feature of the literature is that most studies employ ICT capital or investment as the measure of ICT. Few studies use complex e-business systems or diffusion of broadband among employees within and across firms as the measure of ICT usage. In this study the main purpose is to go beyond the already extensively researched field of investments in ICT hardware and infrastructure, and use instead other proxies for

[6] Previous studies only distinguished between two types of skills so that polarization could not be investigated.

ICT related to broadband usage among employees and diffusion of e-business systems such as enterprise resource planning systems (ERP) and electronic invoicing. These variable are included or can be constructed using Eurostat's Community Survey on "ICT Usage and E-Commerce in Enterprises" from 2006 onwards. The use of ERP systems and electronic invoicing systems are particularly interesting because they tend to improve productivity at the expense of workers. However, skilled and medium skilled workers are likely to benefit from the introduction of ERP systems. .

Few studies have investigated the effects of broadband access on the demand for skilled workers. An exception is the study by Akerman, Gaarder and Mogstad (2015) who investigate whether broadband internet is a complement or a substitute to skilled/unskilled workers. Using Norwegian firm-level data the authors show that increased availability of broadband internet improves the labour outcomes of skilled workers. In particular, a 10 percentage point increase in broadband availability raises wages of skilled workers in that local labour market by about 0.2%. By comparison, the authors find evidence of a decline in wages of low skilled individuals, but no significant effect on their employment rate. Using county level data for the US for the period 1999-2007, Atasoy (2013) finds that broadband access is significantly 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. A drawback of the majority of these studies is that ICT indicators other than broadband use have been not used so far.

2.3 Empirical model

Numerous studies have investigated the relationship between changes in workforce skills and the introduction of information and communication technologies. Industry-level studies typically measure skills by the share of workers (or total wage bill) with higher education within the industry. ICT is measured by expenditures on computing equipment or estimates of the ICT capital stock. The link between different information technology applications and workforce skill intensity can be analyzed using a standard cost function framework (Berman, Bound and Griliches, 1994). The cost function is defined over 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 middle education or no degree (M). Total employment (*L*) is equal to the sum of M and H (L=M+H, in full time equivalents). 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:[7]

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

where *i=1,..,N* are industries at the two-digit level for a given country, *c*, and *t*=2002, 2004,..,2010 refers to every two year period. The dependent variable is the share of workers with a tertiary degree, H_{ict} / L_{ict}. $\ln K_{ict} / VA_{ict}$ is the (log) capital output ratio and $\ln VA_{ict}$ is value added in constant prices while *L* is total employment in full time equivalents. ICT is a vector of variables capturing the use of different ICT applications including 1) the use of Enterprise Resource Planning (ERP), 2) the use of Customer Relationship Management (CRM), 3) the use of Supply Chain Management (SCM), 4) the use of Automated Data Exchange (ADE), and 5) the use of internal linkages of ICT systems. Enterprise Resource Planning (ERP) software typically integrates data management for different functions of the firms such as planning, procurement, sales, marketing, finance and human resources (Hitt et al., 2002). The introduction of ERPs is often associated with significant organisational changes within the firm. Customer Relationship Management (CRM) software aims to collect, process and analyse

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

information related to the firm's customers (Hendricks, Singhal and Stratman, 2007). Supply Chain Management (SCM) software is used to automatically share electronic information about procurement, sales, orders, and inventory with customers and suppliers. Often ERP systems include CRM and SCM applications, so it is difficult to distinguish between the different e-business applications (Hendricks, Singhal and Stratman, 2007).

The *ICT* vector includes also the proportion of internet-enabled employees in firms and the percentage of workers with mobile internet usage are used. 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 or access to broadband internet but also the diffusion within the firm.

We expect a positive relationship between skill intensity and the variables capturing ICT/ internet usage. The explanation for the positive link is that both production factors are complementary to each other. Given that the previous literature find that the link between employment and ICT applications differ by type we include each ICT indicator separately. For the link between total employment and ICT, Atasoy et al. (2013) find that the employment effects of large scale ICT applications such as ERP are significantly higher than for small scale ICT applications such as e-banking and a new website. It would be preferable to use a composite ICT indicator distinguishing between large and small scale ICT applications. However, consistent time series of the ICT indicators are not available. Half of the indicators are only available from 2007 onwards.

In general, causality can go both ways: investment in ICT leads to higher demand for skilled workers, but higher human capital can also be an important precondition for ICT adoption and usage. Moreover, skill intensity is also likely to be endogenous due to common unobservable factors affecting both ICT adoption and demand for skills at the same time. Indeed, a number of studies show that the skills structure of the workforce is an important determinant of ICT adaption and usage. Examples include Bresnahan et al. (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.[8]

The system GMM panel data estimator developed by Blundell and Bond (1998) can be used to account for the correlation of ICT indicators with the error term. 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 for the skill intensity variable, we opt for a dynamic adjustment process. Incorporating the partial adjustment mechanism into the static equation lends the skill share equation in dynamic form:

$$H / L_{ict} = \alpha_i + \alpha_0 H / L_{ict-1} + \beta_1 \ln K / VA_{ict} + \beta_2 \ln VA_{ict} + \phi ICT_{ict} + \lambda_t + \varepsilon_{ict} \qquad [2]$$

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

2.4 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 (for instance, aggregated by industry, firm size or age or both firm size and age). Information on firms is sourced from the

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[8] Given that the number of time periods is five and the number of cross-section units is large, the so-called spurious regress problem can be neglected.

national statistical offices in 14 European countries.[9] 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. This means that workers with a college or university degree are included in this definition. However, information on educational attainment is only available for seven European countries (DK, FI, FR, NL, NO, SE and UK). The data are available for the period 2001-2010. In this study, data at the NACE rev 1.1 two-digit industry level are used where the change in NACE classification from 2008 onwards is adjusted.

Value added is defined as gross output minus intermediate purchases of services and goods. The capital stock is based on either the capital stock or on the book value. Nominal prices (value added and capital) are deflated by EUKLEMS or WIOD two-digit price indexes. Employees are measured in full time equivalents in the majority of countries. The variable *proportion of broadband internet-enabled employee*s builds on information from the survey on ICT usage in firms. The variable includes information both on broadband adoption and on the proportion of employees with internet access.

Table 6 and Table 7 provide descriptive statistics. As can be seen 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 service industries than in manufacturing. In contrast, the capital stock to output ratio is declining over time.

Table 6: Descriptive statistics of the variables (changes median)

	change in the level share or log levels over a two year period (measured in percent or percentage points)						
	% broadband enabled employees	proportion of workers with mobile internet in %	% of firms with ERP	% of firms electronic invoicing	share of workers with a tertiary degree in %	% broadband enabled employees	proportion of workers with mobile internet in %
	manufacturing industries						
2002	#NV	#NV	#NV	#NV	0.8	5.0	-3.3
2004	10.8	6.5	#NV	#NV	1.1	-5.9	8.2
2006	4.8	6.1	#NV	6.8	0.9	-3.3	5.5
2008	3.5	8.9	10.5	4.4	0.6	-3.9	6.7
2010	3.9	10.5	8.6	9.5	0.4	6.6	-14.6
	service industries						
2002	#NV	#NV	#NV	#NV	1.2	-4.5	8.0
2004	10.2	7.7	#NV	#NV	1.3	-9.3	7.1
2006	6.1	7.6	#NV	4.9	0.8	-1.5	7.7
2008	3.4	10.5	7.6	8.6	0.4	1.7	8.0
2010	2.8	12.0	15.8	7.2	0.2	3.8	-4.2

Source: Esslait micro moments database, un-weighted across industries. Table contains data for DK, FI, FR, the NL, NO, SE and the UK. The sample of service industries includes Nace rev 1.1, 50, 51, 52, 60t3, 71t4, 72, 73. Manufacturing contains 15a6, 20, 21, 22, 23a4, 25, 26, 27, 28, 29, 30a3, 31, 32, 34, 35, 36a7.

[9] 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.

Table 7: Descriptive statistics of the variables in levels (median)

	% broadband enabled employees	proportion of workers with mobile internet in %	% of firms with ERP	% of firms electronic invoicing	share of workers with a tertiary degree in %
	manufacturing industries				
2002	22.6	10.2	n.a.	n.a.	8.3
2004	34.6	14.8	n.a.	n.a.	9.3
2006	36.4	19.4	52.9	53.7	9.7
2008	40.3	25.8	58.3	56.9	10.6
2010	43.7	37.4	76.5	68.2	10.6
	service industries				
2002	36.2	11.4	n.a.	n.a.	13.0
2004	49.1	16.6	n.a.	n.a.	14.9
2006	55.5	28.1	20.1	52.3	17.0
2008	59.4	38.4	28.3	54.3	18.7
2010	65.2	54.0	49.9	63.9	19.7

Source: Esslait micro moments database, unweighted across countries and industries. Descriptive statistics is based on data for DK, FI, FR, the NL, NO, SE and the UK. The sample of service industries includes the following industries (based o Nace rev 1.1): 50, 51, 52, 60t3, 71t4, 72 and 73. Manufacturing industries include 15a6, 20, 21, 22, 23a4, 25, 26, 27, 28, 29, 30a3, 31, 32, 34, 35, 36a7.

2.5 Empirical results

Table 8 reports the fixed effects estimates of the relationship between different types of ICT applications and the share of workers with a tertiary degree. Separate estimation results are provided for manufacturing and service industries and for each of the four ICT indicators (see column i to iv). Estimations are based on two-digit industry data for seven European countries measured for every two years during the period 2002-2010. For manufacturing industries the results show that the percentage of firms with enterprise resource planning systems is significantly positively associated with the share of workers with a university degree even after controlling for fixed effects (country industry pairs) and time effects. The share of broadband enabled workers and the share of workers with mobile internet are also both significant at the 10% level. Interestingly, the share of firms with electronic invoicing is also significantly related to the share of highly skilled workers (with a p-value of <0.05). A possible explanation of the positive link is that automated electronic invoicing and payment systems make workers with middle and low education redundant and thereby increase the demand for highly skilled workers.

Table 8: Fixed effects estimates of the impact of different types of information and communication technology on the share of workers with a tertiary degree

	Manufacturing industries											
	(i)			(ii)			(iii)			(iv)		
	coeff.		t	coeff.		t	coeff.		t	coeff.		t
% of workers with access to broadband internet	0.020	*	1.84									
% of workers with mobile internet access				0.014	*	1.94						
% of firms with ERP							0.049	**	2.19			
% of firms with electronic invoicing										0.014	**	2.17
log real capital stock per value added constant prices	0.009	***	2.90	0.015	***	4.39	0.010		1.22	0.004		0.80
log real value added const. prices	0.005	*	1.87	0.017	***	4.59	0.017	*	1.74	-0.007	**	-2.02
year 2004 (ref. category 2002)	0.010	***	3.93	0.010	***	4.01				0.018	***	5.39
year 2006	0.019	***	7.22	0.017	***	6.00				0.021	***	4.46
year 2008	0.025	***	8.58	0.021	***	6.07	0.007	**	2.12	0.027	***	5.77
year 2010	0.030	***	9.55	0.025	***	5.28	0.011		1.63	0.030	***	5.51
constant	0.019		0.46	-0.141	***	-2.69	-0.135		-0.97	0.196	***	3.91
# of observations	527			463			207			352		
# of groups (country 2 digit industry pairs)	112			112			112			112		
R^2	0.461			0.457			0.394			0.467		
	Services industries											
	coeff.		t	coeff.		t	coeff.		t	coeff.		t
% of workers w access to broadband internet	-0.006		-0.33									
% of workers w. mobile internet access				0.047	***	2.74						
% of firms with ERP							0.059		1.52			
% of firms with electronic invoicing										0.004		0.30
log real capital stock per value added con. p.	0.003		0.37	0.006		0.52	0.031		1.43	0.022	**	2.06
log real value added const. prices	-0.002		-0.20	-0.003		-0.19	0.028		0.94	0.014		1.04
year 2004 (ref. category 2002)	0.016	***	3.28	0.012	**	2.08				0.017	**	2.43
year 2006	0.023	***	4.09	0.013	**	2.14				0.008		0.81
year 2008	0.030	***	5.00	0.015	**	2.01	0.011		1.52	0.020	*	1.87
year 2010	0.033	***	5.41	0.013		1.49	0.018		1.52	0.022	*	1.88
Constant	0.271		1.59	0.268		1.36	-0.165		-0.38	0.036		0.18
number of observations	230			91			154			203		
number of groups (country industry pairs)	49			49			49			49		
R^2	0.25			0.43			0.25			0.27		

Notes: *, ** and *** are statistically significant at the 10, 5 and 1% level, respectively. contains data for DK, FI, FR, the NL, NO, SE and the UK. The sample of service industries includes Nace rev 1.1, 50, 51, 52, 60t3, 71t4, 72, 73. Manufacturing contains 15a6, 20, 21, 22, 23a4, 25, 26, 27, 28, 29, 30a3, 31, 32, 34, 35, 36a7.
Source: Esslait micro moments database.

For service industries the use of mobile internet is significant at the 1% level while the remaining indicators are not significant at conventional significance levels. The results for manufacturing industries clearly indicate that increases in the share of firms whose workers have a broadband connection and those who use ERP systems contribute to the skill upgrading of the workforce either by reducing the number of low skilled workers or workers with an intermediate degree, or by raising the demand for highly skilled workers. The results are consistent with the skill biased technological change hypothesis.

In order to give an idea of the magnitude of the correlations, the contribution of the increased ERP usage to skill upgrading can be calculated. The coefficient of 0.049 means that the increase in the use of ERP by 23 percentage points over the period 2006 to 2010 (from 51% to 73% un-weighted across manufacturing industries) accounts for an increase in the share of highly skilled workers by about one percentage point (calculated as 0.011=0.049 X 0.23). Given the increase in the relative demand for highly skilled workers by 4.5 percentage points over the sample period one can conclude that the increase in the percentage of firms with ERP usage accounts for one fourth of the increase in the share of highly skilled workers. These calculations should be interpreted with caution since they do not reflect causal relationships but rather associations.

Furthermore, the share of broadband enabled workers is positive and significant at the 10% level. The coefficient is 0.02 indicating that the increase in the share of broadband enabled employees by 20 percentage points between the period 2002 to 2012 accounted for a 0.4 percentage points increase in the share of workers with a tertiary degree over the period. The contribution of mobile internet is similar to that of broadband enabled employees. Overall the results indicate that the association between an ERP system and the skill intensity is more pronounced than those for broadband internet or mobile internet. A similar conclusion can be drawn for electronic invoicing.

For manufacturing industries the remaining right hand variables are significant and show the expected sign. The capital stock is positive and significant indicating capital skill complementarity. Output measured in value added in constant prices is also positive and significant.

Table 9 in the Appendix shows the two-step system GMM results of the impact of broadband penetration on the relative demand for skilled workers for the total sample including manufacturing and service industries. The GMM estimates use robust standard errors and treat the e-sales variable as predetermined. For specification (ii) the Hansen J-test supports the validity of the instruments at the 1% significance level. The results show a statistically significant and positive relationship between the skill intensity and the proportion of broadband enabled employees. This implies that industries with an increase in the share of workers using broadband internet connections exhibit a higher change in the skill intensity. The short-run coefficient is 0.05, indicating that an increase in the percentage of workers with broadband internet access by 10% is associated with an increase in the skill intensity by 0.5 percentage points. For the remaining ICT and internet indicators it is not possible to run the dynamic panel data model because of the short time series.

We conducted several robustness checks. First, following Berman, Bound and Griliches (1994) we estimated the relative demand for workers with a university degree by OLS in long (two year) differences rather than by a fixed effects model. Unreported results for manufacturing industries again show that the ICT indicators and e-commerce indicators are significant in most of the cases. However, the standard errors based on OLS are higher than that of the fixed effects estimator. Second, we have re-estimated the skill share equation with organizational change and an interaction term of organizational change and different ICT indicators. A number of studies show that the introduction of new computer technologies into the workplace leads to new forms of work organization and other changes in the organisational structure, thus increasing the demand for more skilled workers (Bartel, Ichniowski and Shaw, 2007; Chennells and Van Reenen, 2002; Caroli and Van Reenen, 2001; Piva, Santarelli and Vivarelli, 2005). However, unreported results show that the inclusion of these variables does not increase the fit of the model.

2.6 Conclusions

This study provides first 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 investment in computers or other investments in information technology hardware and increases in the share of skilled labour within a given industry. In this study a special emphasis is put on specific ICT applications - such as the so-called e-business systems (or Enterprise Systems -ES) - and other e-business applications - such as electronic invoicing - 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 internationally comparable industry level data from seven European countries for the years 2002-2010. 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. In particular, for manufacturing industries, the share of broadband enabled employees, share of workers with mobile internet, use of enterprise resource planning systems and electronic invoicing are all significantly positively related with the share of workers with a university degree.

However, for service industries the use of mobile internet is significant while the remaining indicators are insignificant. For manufacturing industries, the association between use of ERP systems and skill intensity is more pronounced than those for the remaining ICT indicators. On average across manufacturing industries the increased usage of ERP systems accounts for one fourth 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 for high-skilled labour. Our results confirm results from previous studies for the first digital revolution. The current digital revolution also favours qualified workers.

This study has several limitations that should be mentioned. First, we use educational attainment as a measure of skills. It is well know that educational qualification is only a proxy variable for skills. Alternatively, employment can be disaggregated by tasks. Several studies suggest that routine jobs are likely to be more affected by ICT than non-routine jobs. Future work should employ other measures such as tasks or employment by occupational category. Information on occupations can be drawn from the European Labour Force Survey. Second, given the available data it is not possible to distinguish between unskilled and middle educated workers. 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 middle educated workers (Michaels, Natraj and Van Reenen, 2010).

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2.8 Appendix

Table 9: System GMM estimates of the impact of broadband internet enabled employees on the share of workers with a tertiary degree

	(i)			(ii)		
	coeff.		t	coeff.		t
share of workers with tertiary degree t-2	0.92	***	15.42	0.96	***	15.20
broadband enabled employees in percent t	0.05	**	2.22	0.05	*	1.78
log value added constant prices t	0.00		-0.30			
year dummy 2004 (ref 2002)	0.00		0.55	0.00		-0.23
year dummy 2006	0.00		-0.79	0.00		-0.83
year dummy 2008	-0.01		-1.46	-0.01	**	-2.21
year dummy 2010	-0.01	**	-2.48	-0.01	**	-2.30
constant	0.01		0.34	0.00		-0.48
broadband enabled employees in percent t	0.59				1.34	
# of observations	758				758	
# of groups (country industry pairs)	180				180	
number of instruments	28				28	
Hansen test (p-value)	0.00				0.00	

Note: ***, ** and * denote significance at the 1, 5 and 10 per cent levels. The group of industries include 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, the NL, NO, SE and the UK. 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 short run impact of e-sales on labour productivity is equal to the short-run coefficient (0.05). This coefficient refers to the impact that occurs in year (t). The long-run impact is calculated as the short-run coefficient divided by the adjustment parameter.
Source: ESSLait Micro Moments Database and own calculations.

Study 3. ICT/e-commerce activities as an enabler of technological and organisational innovations

3.1 Abstract

This study investigates the relationship between technological and organisational innovations, and ICT usage/e-commerce and internet technologies. The data is based on disaggregated data by firm size/industry for 12 European countries for the period 2002-2010. The empirical results controlling for fixed effects (industry-size-country pairs) and time effects show that the sales share of new market products is significantly positively related with both the percentage of workers with mobile internet access and e-procurement activities. Sharing electronic data also contributes to product innovations. Another important result of the study is that organisational change and enterprise resource planning systems are significantly positively related, indicating that the changes in the organisational structure are critical for successful ERP implementation.

Keywords: ICT usage, e-procurement, technological innovations, organisational change.

3.2 Introduction

The aim of this section is to investigate the relationship between different types of ICT applications and both technological innovations and organisational change where technological innovations are measured by product and process innovations. A currently prominent hypothesis is that information and communication technologies are an important enabler of product and process innovations. The rationale behind this is that ICTs increase the speed of diffusion of information, enable networking activities among firms and allow closer links between firms and clients (Spiezia, 2011). Similarly, there is an ongoing discussion about the relationship between the introduction of enterprise information systems and changes in the organizational structure. The management literature shows the importance of changes in the organizational structure for successful ERP implementation (Bloom et al., 2009; Aladwani, 2011). In particular, ERP systems can have important implications for the organisational structure of the firm. They imply changes to the hierarchical structure, to the decision-making strategies, to responsibilities and to the organisation's culture (Davenport, 1998). ERP systems allow organisations to streamline their management structures - creating flatter, more flexible and democratic organisations - by providing real-time access to operating and financial data. On the other hand, they also involve the centralisation of control over information and the standardisation of processes, which are qualities that are more consistent with hierarchical organisations (Davenport, 1998). Often the outcome of an ERP implementation is flatter hierarchies and the distribution of decision-making to the lowest possible organisational level.

Previous studies confirm that ICTs play an important role in enabling technological innovations (e.g. Leeuwen, 2008; Santoleri, 2013; Spiezia, 2011; Todhunter and Abello 2011; Kleis et al., 2012). For instance, Spiezia (2011) finds that ICT activities are an enabler of innovation using firm level data in several OECD countries. Using firm level data for Australia, Todhunter and Abello (2011) find a strong relationship between ICT intensity and innovation activity. In particular, firms which use sophisticated types of ICT are significantly more likely to introduce novel innovations. Innovations are defined according the degree of novelty of products in the same industry, on the home market and on the world market. More recently, Kleis et al (2012) also find that ICTs contribute to the innovation process. However, the empirical results suggest that ICTs alone do not lead to breakthrough innovations. Accordingly, radical innovations are more dependent on other factors such as investment in R&D and the tacit knowledge of R&D scientists and engineers. In contrast to the majority of studies, Arvantitis et al (2013) do not find evidence that ICT acts as an enabler of product innovations. In addition, the authors do not find any effect for e-procurement or e-sales. The authors conclude that at the time of data collection, namely 2005, the level of e-sales and e-procurement was rather low.

Overall, these studies are difficult to compare because they differ regarding their methodology, country coverage and definition and measurement of the innovation and ICT indicators. A striking feature of the literature is that few studies investigate the link between organizational change and sophisticated ICT applications such as enterprise information systems.

The main contribution of the present study is to provide new empirical evidence on the relationship between different ICT applications and both organisational change and technological innovations using an internationally comparable data set that includes several European countries.

The chapter is structured as follows: Section two introduces the empirical model. Section three describes the data and provides descriptive statistics, while section four presents the empirical results, and section five concludes.

3.3 Empirical model

In this section we introduce the empirical model of the relationship between ICT/ e-commerce activities and technological innovations measured as product and process innovations. According to Schmookler innovation output is also a function of demand. This is the so-called demand-pull hypothesis. Using disaggregated data by firm size and industry affiliation the model can be specified as follows:

$$TURNMAR_{isct} = \alpha_{isc} + \alpha_1 ICT_{isct} + \alpha_2 \ln Y_{isct} + \lambda_t + \varepsilon_{isct} \quad [1]$$

where *i=,1...,5* denotes the industry, *s=1,..,.4* the size class, *c=1,..,12* the country and *t=2002, 2004,...,2010* the time. *Ln* denotes the natural logarithm. TURNMAR denotes the share of turnover in new or improved products that are new to the market. Alternatively, the share of firms with new or significantly improved products or services and the share of firms with process innovations are used. *ICT* denotes different ICT indicators including the percentage of workers with access to broadband internet, the percentage of workers with mobile access to internet, e-business systems (such as enterprise resource planning, CRM, sharing electronic data) and e-commerce activities. *Y* denotes value added in constant prices and λ_t denotes time effects. ε_{isct} is the usual error term and assumed to be identically and independently distributed with a zero mean and constant variance, i.e. $\varepsilon_{it} \sim IID(0,\sigma^2)$. α_i accounts for unobservable time-invariant individual effects (here industry-size-country pairs). Given that innovation activities based on the CIS data are only available every two years we suggest specifying a static specification rather than a dynamic specification. Applying a dynamic model leads to loss of observations. Furthermore, Raymond et al, (2010) find that past innovation output has only a small effect on current innovation output. Therefore, the bias of omitting lagged innovation output is likely to be small. The innovation equation can be estimated by the fixed effects model.

Another empirical model relates organisational change to different ICT and e-commerce indicators:

$$ORGIN_{isct} = \alpha_{isc} + \alpha_1 ICT_{isct} + \alpha_2 \ln Y_{isct} + \lambda_t + \varepsilon_{isct} \quad [2]$$

where ORGIN denotes the percentage of firms with organisational innovations. The right hand variables are the same.

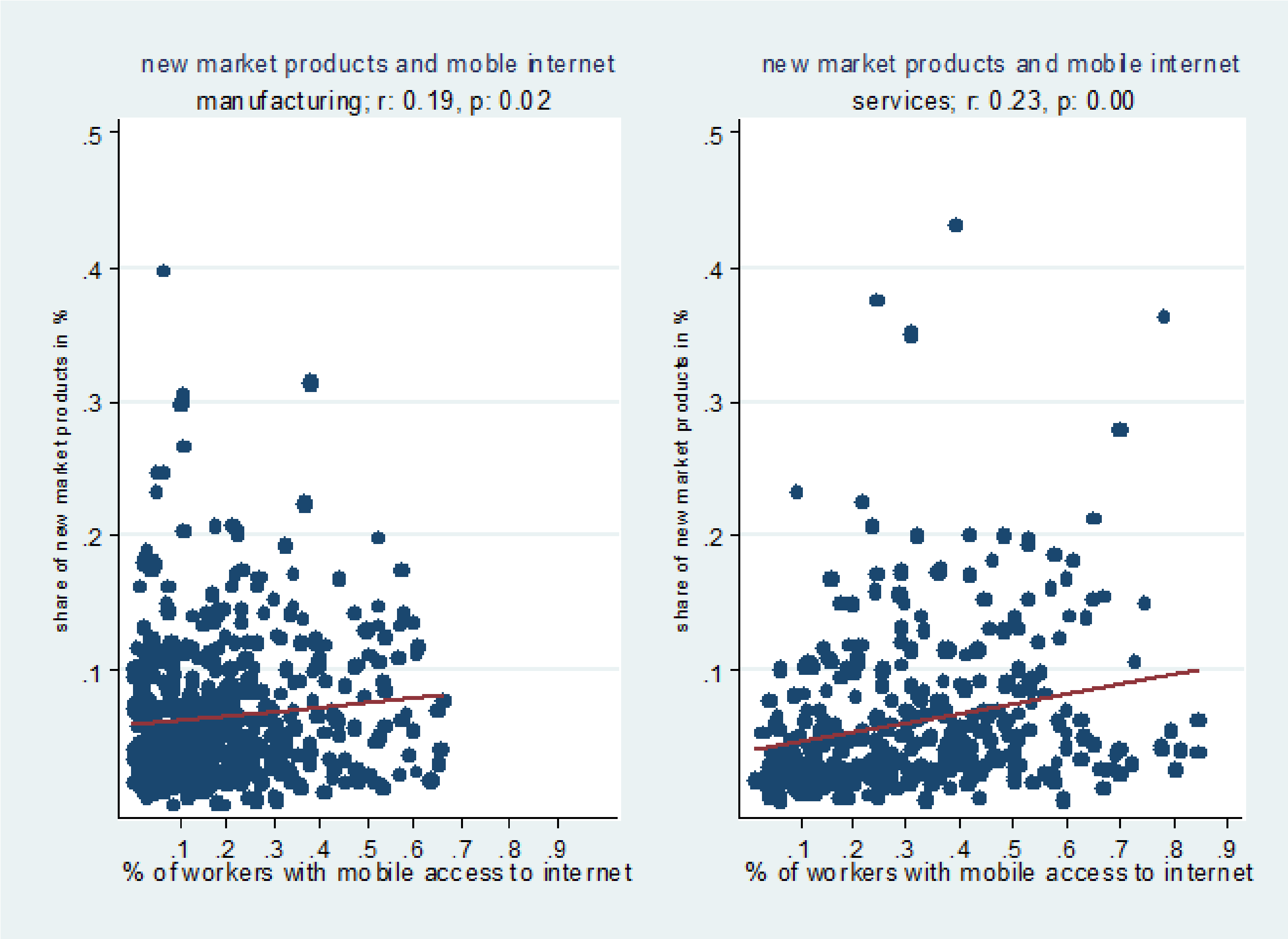
3.4 Data and descriptive statistics

The data for this analysis are drawn from the ESSLait Micro Moments Database (MMD) (see previous section). This database includes micro-aggregated information on firms sourced from the national statistical offices in 14 European countries (i.e., Austria, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Sweden, Slovenia and the United Kingdom). In this section we use information from the structural business statistics, ICT usage and e-commerce survey, and Community innovation survey. Data refers to the period 2001-2010. The data is available at the two-digit industry level and in several other dimensions such as size class, age class, ICT intensity, innovation activity, ownership, affiliation and international experience. In this empirical application, data aggregated by both size class and broad industry groups are employed (for the classification of the industry groups see Table 12 in the appendix). Using a unbalanced panel comprised of four size classes, five industries, 12 countries and up to five years (2002,...,2010) the number of available observations is about 900 of which 550 refer to manufacturing and 350 to services. Information on the sales share of market novelties and the percentage of firms with organisational changes is based on the CIS. Value added is based on the structural business statistics while the remaining ICT/e-commerce indicators are based on the ICT usage/e-commerce survey.

Nominal value added is deflated by EUKLEMS or WIOD price indexes (www.euklems.net and www.wiod.org). Value added is defined as gross output minus intermediate purchases of services and goods. The ICT variables are either measured as the percentage of firms in an industry using the respective technology or a quantitative measure (i.e. percentage of employees using the measure or sales share).

In order to obtain a first idea of the strength of the relationship between product innovations and ICT activities, scatter plots are conducted. Figure 4 plots the sales share of new market products against the percentage of workers with mobile internet access distinguishing between manufacturing and services industries. The time period refers to the period 2002-2010. For both manufacturing and services industries we find a significant and positive correlation between product innovations and the percentage of workers with mobile internet access. This indicates that the higher the share of workers with mobile internet access at work the higher the innovation performance in a given size class and industry. However, the magnitude of correlations is rather low (0.19 for manufacturing and 0.23 for services). Similar evidence can be observed for e-procurement activities (Figure 5). Here the correlations for manufacturing and services are 0.13 and 0.09 respectively where the latter is only significant at the 10% level.

Figure 4: Product innovation and mobile internet access (2002-2010)

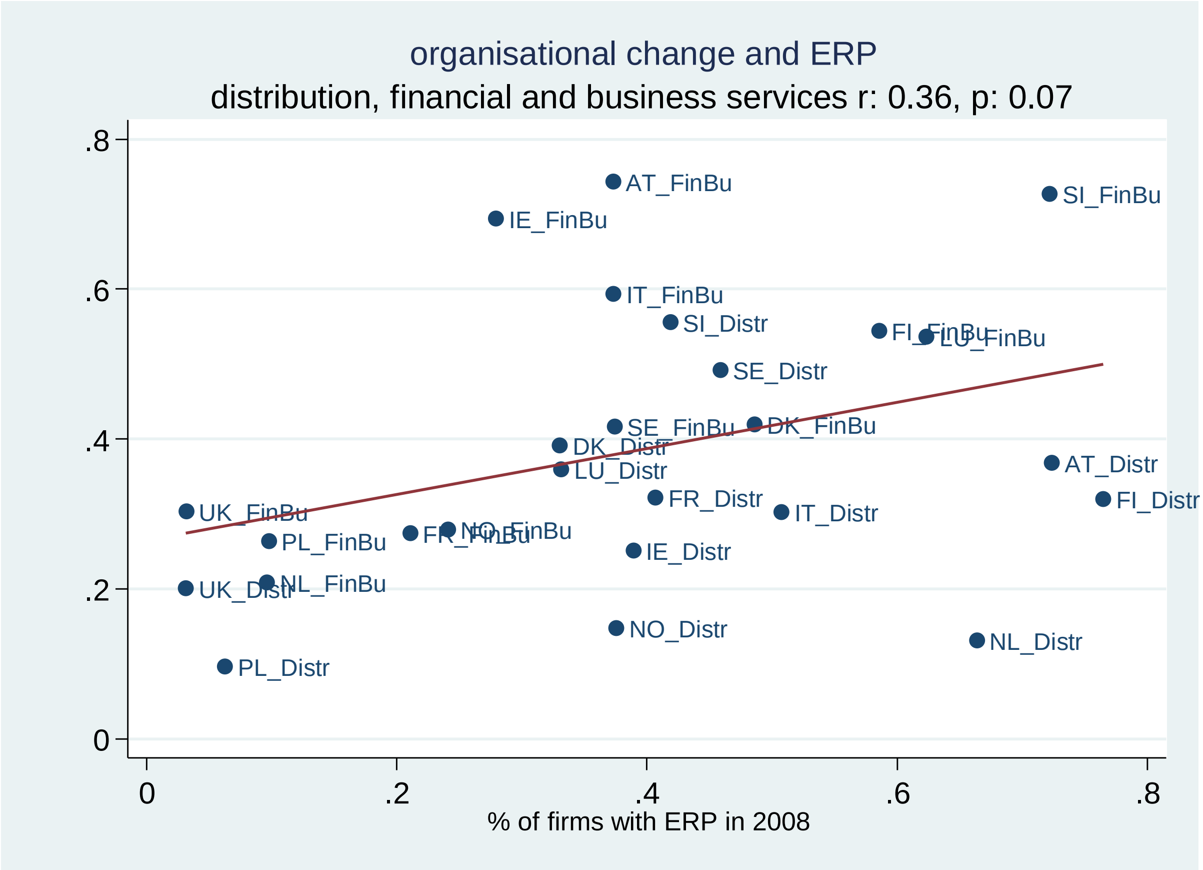


Note: The sample is based on industry level data for 12 EU countries (i.e. AT, DK, FI, IE, IT, the NL, NO, PL, SE, SI and the UK) and five industries (consumer goods, intermediate goods and investment goods, distribution services, financial services and business services). Source: ESSLait Micro Moments Database.

Figure 5: Product innovation and e-buying activities (2002-2010)

Note: The sample is based on data disaggregated by industry and size class for 12 EU countries (i.e. AT, DK, FI, IE, IT, the NL, NO, PL, SE, SI and the UK) and five industries (consumer goods, intermediate goods and investment goods, distribution services, financial services and business services). Source: ESSLait Micro Moments Database.

Figure 6: Organisational change and enterprise resource planning systems, large firms (2008)



Note: The sample is based on disaggregated data of large firms in 12 EU countries (i.e. AT, DK, FI, IE, IT, the NL, NO, PL, SE, SI and the UK) and two service industries (distribution, financial and business services). Source: ESSLait Micro Moments Database, own calculations.

Concerning the second hypothesis on the relationship between organisational change and ERP we find that both variables are significantly correlated. For large firms the correlation coefficient is 0.36 and significant at the 10% level (Figure 6). Unreported results for the other size classes also show a positive coefficient but the correlations are not significant at the 10% level. The correlations should be interpreted with caution because they cannot control for unobservable fixed (group) and time effects. Nevertheless they could provide a first indication of possible associations.

3.5 Empirical results

Table 10 shows the results of the fixed effects model of the determinants of the turnover share of new market products. In addition, results are reported for the alternative measures of technological innovations, namely the share of firms with production innovations and the share of firms with process innovations. Separate models are estimated for manufacturing and service industries. We report results for three out of 12 ICT and ecommerce variables which are at least partly significant. These include the percentage of workers with mobile access to the internet, the percentage of orders over the internet and the percentage of firms sharing electronic data. Unreported results show that the remaining ICT and e-commerce indicators do not have a significant impact on the different types of technological innovations. This holds true for the share of broadband enabled employees, e-sales activities and ERP usage.

Table 10: Results of the fixed effects model on the relationship between technological innovations and ICT

	Dep. var: share of turnover due to new market products					
	manufacturing			services		
	(i)			(ii)		
	coeff.		t	coeff.		t
% of workers with mobile access to internet	0.04	*	1.80	0.07	**	2.44
log value added in constant prices	0.00		0.27	-0.01		-0.89
constant	0.03		0.27	0.14		1.33
R^2 within	0.02			0.03		
number of observations	543			372		
number of groups	140			96		
	(iii)			(iv)		
	coeff.		t	coeff.		t
% of orders through internet	0.10	*	1.76	0.16	***	2.63
log value added in constant prices	0.01		1.04	0.00		0.00
constant	-0.04		-0.49	0.04		0.43
R^2 within	0.03			0.06		
number of observations	539			364		
number of groups	140			96		
	(v)			(vi)		
	coeff.		t	coeff.		t
% of firms sharing electronic data	0.08	**	2.93	-0.01		-0.42
log value added in constant prices	0.01		0.11	0.11	***	2.96
constant	-0.09		-0.08	-1.64	***	-2.90
R^2 within	0.32			0.54		
number of observations	176			120		
number of groups	140			96		
	Dep. var: share of firms with product innovations					
	manufacturing			services		
	(i)			(ii)		
	coeff.		t	coeff.		t
% of workers with mobile access to internet	-0.12		-1.29	0.03		0.40
log value added in constant prices	0.06	*	1.95	0.12	***	6.75
constant	-0.36		-0.84	-1.53	***	-5.54
R^2 within	0.05			0.19		
number of observations	566			388		
number of groups	152			104		
	(iii)			(iv)		
	coeff.		t	coeff.		t
% of orders through internet	0.00		0.00	-0.15		-0.97
log value added in constant prices	0.07	***	2.60	0.13	***	7.45
constant	-0.59		-1.50	-1.70	***	-6.26
R^2 within	0.00		0.00	-0.15		-0.97
number of observations	539			364		
number of groups	140			96		
	(v)			(vi)		
	coeff.		t	coeff.		t
% of firms sharing electronic data	0.56	***	2.73	0.19		0.88
log value added in constant prices	-0.20		-0.35	0.76	**	2.52
constant	3.02		0.37	-11.37	**	-2.48
R^2 within	0.29			0.42		
number of observations	188			128		
number of groups	152			104		
	Dep. var: share of firms with process innovations					
	manufacturing			services		
	(i)			(ii)		
	coeff.		t	coeff.		t
% of workers with mobile access to internet	-0.12		-1.35	0.04		0.45
log value added in constant prices	0.06	**	2.19	0.11	***	5.51
constant	-0.46		-1.14	-1.27	***	-4.35
R^2 within	0.06			0.16		
number of observations	556			388		
number of groups	152			104		
	(iii)			(iv)		
	coeff.		t	coeff.		t
% of orders through internet	-0.07		-0.35	-0.13		-0.81
log value added in constant prices	0.08	***	2.93	0.12	***	6.25
constant	-0.67	*	-1.84	-1.46	***	-5.11
R^2 within	0.06			0.17		
number of observations	559			380		
number of groups	152			104		
	(v)			(vi)		

	coeff.		t	coeff.		t
% of firms sharing electronic data	0.51	**	2.64	0.18		0.74
log value added in constant prices	-0.21		-0.40	0.75	**	2.31
constant	3.35		0.44	-11.24	**	-2.27
R^2 within	0.24			0.30		
number of observations	188			128		
number of groups	152			104		

Note: ***, ** and * denote significance at the 1 , 5 and 10% level. All regressions include time dummy variables that are not reported.

The results show that the percentage of workers with mobile internet access is positively and significantly associated to the share of new market products. The positive coefficient can be observed for both manufacturing and service industries. The coefficient of 0.07 for services means that an increase in the percentage of workers with mobile internet access by 10 percentage points is associated with an increase in the sales share of new market products by 0.7 percentage points. Given that the sales share of new market products in services industries has a value of 4% (median unweighted across industries, size classes), the magnitude of the association is not negligible.

Specification (iii) and (iv) show that new market products and e-commerce activities measured as the sales share of orders over the internet are significantly positively related (Table 10 upper panel). This indicates the higher the share of order transactions over the internet the higher the sales share of new market products. Again, the strength of the association is larger in service industries than in manufacturing. The importance of e-commerce activities as an enabler of product innovations is a new finding in the literature.

Specification (v) and (vi) show the results for the impact of e-business systems measured as the percentage of firms sharing electronic data. The results are mixed. While there is a positive relationship for manufacturing industries, there is no significant association for service industries. Overall, the results partly support the results of Spiezia (2011) that ICT is an enabler of product innovations.

The control variable value added in constant prices is not significant in the majority of cases. This indicates that the product innovations are independent from changes in output. This stands in contrast with Schmookler's demand-pull hypothesis indicating that innovation is a function of demand (Kleinknecht and Verspagen 1990).

When product innovations are measured by the share of firms with new products, mobile internet access and e-procurement are no longer significant at the conventional significance levels. The same holds true for process innovations (see table 10 middle and lower panel).

Note that the goodness of fit of the model is rather low. The (within) R^2 of the specifications (i) to (iv) ranges between three and 6% indicating that a large part of the variation of the sales share of new market products over time cannot be explained by the model. Note that the relatively low R-squared of the within estimator is not uncommon given that this estimator only uses the time variation within each cross section of observation.

As a robustness check we have estimated separate equations by size class. Unreported results show that the positive relationships can be observed for each size class. However, the standard errors are much larger compared to the regression for the total sample.

Table 11 shows the results of the fixed effects model of the determinants of the percentage of firms with organisational changes. For services industries the percentage of firms with ERP systems and the percentage of firms with organisational change are significantly positively related ($p<0.10$). However, the correlation is rather low. For manufacturing industries there is a significant correlation between the percentage of firms sharing electronic data and the percentage of firms performing organisational change.

Table 11: Fixed effects results of the determinants of organisational change

	manufacturing			services		
	(i)			(ii)		
	coeff.		t	coeff.		t
% of firms with enterprise resource planning	0.01		0.09	0.13	*	1.70
log value added constant prices	0.02		0.33	0.03		0.31
time dummies	Yes			yes		
constant	0.09		0.10	-0.08		-0.05
R^2: within	0.02			0.07		
number of observations	274			192		
number of groups	152			104		
	(iii)			(iv)		
	coeff.		t	coeff.		t
% of firms with sharing electronic data	0.48	**	2.17	0.30		1.13
log value added constant prices	-0.40		-0.66	0.65	*	1.81
time dummies	Yes			yes		
constant	6.10		0.70	-9.60		-1.74
R^2: within	0.14			0.23		
number of observations	188			128		
number of groups	152			104		

Note: The dependent variable is the percentage of firms with organisational change. ***, ** and * denote significance at the 1%, 5% and 10% level.

3.6 Conclusions

This section has investigated the relationship between innovation activities and ICT and e-commerce activities using disaggregated data at the industry and size class level for 12 European countries. Innovation activities are broadly defined including both product innovations and organisational change. A special feature of the data is that they are harmonized and internationally comparable. The empirical results controlling for fixed effects (industry-size-country pairs) and time effects show that the sales share of new market products is significantly positively related with both the percentage of workers with mobile internet access and e-procurement activities. Sharing electronic data also contributes to product innovation. Another important result of the study is that organisational change and enterprise resource planning systems are significantly positively related, indicating that changes in the organisational structure are critical for successful ERP implementation. However, a number of other ICT indicators do not play a role in either product or organisational innovations. These include the percentage of workers with broadband internet.

Fixed effect estimates show that an increase in the share of firms with e-procurement activities by one percentage point leads to an increase in the sales share of new market products in manufacturing and services by 0.1 and 0.16 percentage points, respectively. There is also some evidence that ICT and organisational change are positively associated.

There are several directions for future research. One possible idea is to separately investigate the impacts for different size classes, and for young and old firms. It is likely that the relationships differ between SMEs and large firms. Another interesting direction of future work is to estimate the indirect effects of ICT. It is likely that broadband use and e-commerce activities affect productivity indirectly through their effects on product innovations.

3.7 Literature

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3.8 Appendix

Table 12. EUKLEMS Industry definitions (NACE 1.1)

	broad industy groups
Elecom	ELECTRICAL MACHINERY (30t33), POST AND COMMUNICATION SERVICES
MexElec	TOTAL MANUFACTURING, EXCLUDING ELECTRICAL (ConsG+ IntmdG+ InvesG)
ConsG	Consumer manufacturing (15t16, 17t19, 36t37)
IntmdG	Intermediate manufacturing (20, 21t22, 23,24, 25, 26 27t28)
InvesG	Investment goods, excluding hightech (29,34t35)
OtherG	OTHER PRODUCTION (C;E,F)
MServ	MARKET SERVICES, EXCLUDING POST AND TELECOMMUNICATIONS (Distr+FinBu)
Distr	DISTRIBUTION (50t52 60t63)
FinBu	FINANCE AND BUSINESS, EXCEPT REAL ESTATE (J, 71t74)
Pers	PERSONAL SERVICES (H,O,P)
NonMar	NON-MARKET SERVICES (L,M,N, 70)
	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. eqpt.
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	Trade, hotels, restaurants
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; oth. bus. svc.
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

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