Title

ICT use by households and firms in the EU:

Links and determinants from a multivariate perspective

Abstract

This paper investigates the use of combined patterns of information and communications technologies (ICT) by households and firms in the EU at the regional level. Using canonical correlation analysis, we identify a pattern defined by the regions that combine high levels of ICT use in households and firms. This pattern is explained primarily by institutional factors, knowledge-intensive services and economic development variables. A divide between southern and northern, and western and eastern regions is detected in this pattern. We also identify a second pattern that captures ICT use within firms (not related to the first), predominantly determined by educational variables and some economic factors. This pattern does not exhibit the geographical digital divide found in the first.

Key words: ICT use, digital divide, European regions, canonical correlation analysis

JEL Classification: O33, R11

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1. Introduction

Within the Europe 2020 strategy, the Digital Agenda for Europe (European Commission, 2014) views information and communications technologies (ICT) as one of the key areas for economic growth and job creation. At the regional level, the Cohesion Policy 2014–2020 program also identifies ICTs as one of the pillars for European regional development (European Commission, 2010a).

The literature has demonstrated ICT impacts on both productivity and economic growth at different levels (e.g., Cardona, Kretschmer, & Strobel, 2013; Dedrick, Gurbaxani, & Kraemer, 2003). Researchers have also emphasized that to guarantee its effects, ICT has to be used in a strategic and transformative way (Capello & Spairani, 2006). In this vein, the progress toward a digital economy in Europe involves boosting ICT use in different types of environments, such as ICT use at home and at work, to facilitate the e-skills acquisition needed for professional capabilities (OECD, 2013) and thus derive wide benefits from ICT impacts. At the regional level, the literature has also stressed that ICT diffusion with potential economic and social impacts requires a multi-dimensional approach that takes into account the fact that traditional boundaries between ICT use by households and employees are increasingly less evident (Hughes et al., 2008). Some authors have also highlighted that ICT diffusion requires a systemic perspective that considers the importance of the interactions and links among the several agents that contribute to facilitating tacit knowledge transfer (Storper & Venables, 2004) in relation to ICT use, as well as the collective learning processes that may favor strategic use at the local and regional levels (Capello & Spairani, 2004; Camagni & Capello, 2005, 2013).

The relevance of ICT impacts justifies researchers' interest in investigating the main drivers of ICT diffusion at different levels. Most of the studies have explored ICT use determinants at the firm level (e.g., Bayo-Moriones & Lera-López, 2007; Haller &

Siedschlag, 2011), and to a lesser extent at sectoral and country-levels (e.g., Cruz-Jesus, Oliveira, & Bacao, 2014; Domenech, Martinez-Gomez, & Mas-Verdú, 2014). In contrast, literature on ICT diffusion at the regional level in Europe is still very scarce. In addition, the empirical studies available have traditionally focused on explaining ICT use by households (Billón, Ezcurra, & Lera-López, 2008; Vicente & López, 2011). Only Milicevic and Garies (2003) have investigated ICT use at work. Their study, undertaken for 28 European regions in 2002, used a bivariate and descriptive analysis to show how ICT use supported certain work-related activities. In this context, the objective of the paper is twofold. First, we aim to investigate whether ICT use in households and ICT use by firms present common or differentiated patterns at the regional level. Second, we explore the main drivers that explain the patterns detected.

The paper makes three main contributions to the current state of ICT diffusion. First, it contributes to the empirical literature on ICT use by providing new evidence regarding ICT diffusion at the regional level as, in comparison to previous studies, this research extends the analysis to ICT use by firms. Second, this paper contributes to shedding light on the regional digital divide by exploring the differences across European regions in detecting common and differentiated patterns of ICT diffusion. Third, we employ a multi-dimensional framework to explore simultaneously ICT use by households and firms. Most of the earlier studies have tended to employ multiple regression analysis to explain a single dependent variable or an ICT index (e.g., Andrés et al., 2010; Chinn & Fairlie, 2007, Vicente & López, 2011). Unlike most previous works, this paper provides a multivariate perspective, using canonical correlation analysis (CCA).

From a public policy perspective, given the importance of promoting ICT diffusion within the aforementioned European strategy, and taking into account the key role played by local and regional authorities in implementing the Digital Agenda for Europe (European

Commission, 2014), new empirical evidence on patterns of ICT diffusion could be of interest in increasing knowledge to map and explain ICT diffusion at the regional level.

Following this introduction, the remainder of the paper is organized as follows. In the second section we review the literature. The third section presents the research model, variables, and data employed. The fourth section explains the methodology applied. The fifth section provides the empirical analysis. The final section presents the main conclusions and policy implications of our work.

2. Literature review

ICT adoption and use have commonly been explained by diffusion theory. Epidemic models (Mansfield, 1968) explain technology diffusion through the spread of information regarding technology and the learning process associated with its use (Geroski, 2000; Karshenas & Stoneman, 1995). Potential adopters obtain information on new technology as the diffusion process spreads out through human interactions. Heterogeneity models (Rosenberg, 1972) and more specifically rank models, take into account heterogeneity among adopters to explain observed diffusion patterns. The empirical literature has explored the influence of adopters' characteristics on ICT diffusion at different levels of analysis, such as the firm (Bach, Zoroja, & Vuksic, 2013; Haller & Siedschlag, 2011; Martin & Omrani, 2015), sector (Domenech et al. 2014; Galliano & Roux, 2008), and country (Cruz-Jesus et al., 2012; Pick & Nishida, 2015; Vicente & López, 2006) levels, studies at the firm level being the most common.

At the regional level, several strands of the literature have also emphasized the importance of regional characteristics for technology diffusion and the relevance of "regional innovation cultures" to facilitate the transformative use of ICT (Hughes et al., 2008). From the regional innovation system approach (Lundvall, 1992; Nelson, 1993) to the "learning regions" notion (Morgan, 1997), technology diffusion is increasingly seen as the result of the interaction of a large number of different economic, social, and institutional factors.

Individuals and firms take part in various forms of information and knowledge interactions at the local level. In this line, rather than focusing primarily on individual firms and their activities, the new contributions stress the need for a systemic approach that also takes into account local environmental characteristics (Camagni, 1991). Innovative capacity and human capital endowment, together with a favorable institutional framework, may favor local synergies and interpersonal interactions among several actors (firms, customers, suppliers, institutions, etc.), favoring tacit knowledge transfer (Capello & Spairani, 2006; Storper & Venables, 2004), as well as collective learning processes that may enable a strategic use of ICT (Camagni & Capello, 2005; Capello & Spairani, 2004; Hughes et al., 2008).

In a similar vein, within the framework of the knowledge spillover literature (Fujita & Mori, 2005)and considering information spillovers from ICT users to non-ICT users, some authors have studied whether the diffusion and use of some technologies may materialize to a larger extent in areas with higher population sizes and densities, such as urban areas, where a higher level of knowledge spillover and network effects may be registered and where tacit knowledge may more easily be transmitted (Gaspar & Glaeser, 1998; Schleife, 2010). Highly populated areas with more abundant resources would engender lower ICT access costs and facilitate its diffusion (Karshenas & Stoneman, 1995).

At the regional level, however, the evidence on the determinants of ICT diffusion is still very limited. Most of the empirical evidence on ICT adoption at the regional level has referred to specific technologies in the US (Grubesic, 2006; Kolko, 2000). Empirical works related to European regions are less common given the lack of regional data. Some papers have elaborated rankings of European regions in terms of ICT adoption. For example, Vicente and López (2011), considering five different household ICT indicators, find that regions in the Nordic countries, the Netherlands, and the UK are at the top of the classification. Most of the regions ranked at the bottom are those of Southern Europe and those countries that have recently been integrated in the EU. In addition, the authors point to a significant digital divide between European regions.

The few papers explaining ICT adoption at the regional level mainly focus on ICT adoption by households. For instance, Billon, Ezcurra, and Lera-López (2008) show the relevance of gross domestic product (GDP) per capita, unemployment rate, population density, and stock of human capital in explaining the distribution of internet users for a sample of 76 regions in the EU-15. Taking a different perspective, Tranos and Gillespie (2009) consider 1,206 European regions (NUTS3) in the EU-25 and analyze the factors that influence the likelihood of European cities being connected to Internet networks. They obtain four types of factor: the level of economic development, the role of the service sector and the knowledge economy, the geographical structure (percentage of urban population, level of population density), and transport infrastructure. More recently, Vicente and López (2011) have investigated the determinants of ICT adoption by households in 164 European regions, finding that the level of GDP per capita and the percentage of persons employed in science and technology positively influence ICT adoption at the regional level, whereas the unemployment rate and the population over 65 years exercise a negative influence.

Specific regional studies on ICT adoption by firms in the EU are less common. A preliminary and very exploratory paper developed by Milecevic and Gareis (2003) considering different ICT used by households and workers analyzes the distribution of ICT among a sample of 21 European regions. The authors show that specific regional characteristics and ICT endowment explain higher ICT use in densely populated areas, which are expected to be more specialized in the service sector and may therefore also be more specialized in the use of some technologies.

Using different explanatory methodologies, others papers have analyzed the key drivers of ICT use within firms in the EU at the regional level. For example, Billon, Marco, and Lera-

López (2009) examine the regional adoption of websites by firms in European regions using a sample of 239 NUTS2 regions. They show that GDP per capita, population density, education, and sectoral composition are positively related to the geographical distribution of firm websites. Nevertheless, the literature has focused on the analysis of specific European countries. For example, Martinelli, Serrecchia, and Serrecchia (2006), looking at Italian regions, show that domain names registered by firms are explained predominantly by economic variables (added value per employee, unemployment rate, income per capita, etc.) and educational attainment. Other studies have emphasized the relevance of being located in a densely populated area to explain ICT adoption by firms in Spain (Domenech et al., 2014) and France (Galliano & Roux 2008; Galliano, Roux & Soulié, 2011).

3. Research model, variables, and data

Taking into account previous studies in the field, first we investigate whether there are common or differentiated patterns of ICT use by firms and households at the regional level. Second, we explore the main determinants that explain these patterns. We propose a research model in which the combined uses of interactions between different uses of ICT (i.e., ICT use at home and at work) are explained by economic, social, locational, and institutional characteristics (Standing, Sims, & Love, 2009). These features might facilitate knowledge flows in relation to ICT use and therefore its diffusion at the regional level. In general terms, the model can be expressed as:

$$F(y_1, y_2, \dots y_q) = G(x_1, x_2, \dots x_p) \tag{1}$$

where $y_1, y_2, \dots y_q$ is the set of dependent variables and $x_1, x_2, \dots x_p$ is the set of independent variables. The technique couples pairs of linear combinations of variables in each set, the proposed model being as follows:

$$\boldsymbol{Y\beta} = \beta_1 IU + \beta_2 PC + \beta_3 EC + \beta_4 ERPC + \beta_5 ERIU \tag{2}$$

$$\boldsymbol{X\alpha} = \begin{aligned} &\alpha_1 TotRD + \alpha_2 HTEM + \alpha_3 KISE + \alpha_4 Service + \alpha_5 EconActiv + \alpha_6 LifeLong + \alpha_7 PopTer \\ &+ \alpha_8 GDP + \alpha_9 PopAge + \alpha_{10} PopDen + \alpha_{11} Urban + \alpha_{12} GQ + \alpha_{13} FisDec + \alpha_{14} CAPITAL \end{aligned}$$

The set of dependent variables consists of five variables that include different technologies and different ICT uses. Three variables measure ICT use at home and two measure ICT use at work. These variables are: percentage of individuals regularly using the Internet (IU), percentage of individuals using a computer (PC), percentage of individuals ordering goods and services online (EC), percentage of employees regularly using a computer at work (ERPC), and percentage of employees regularly using the Internet at work (ERIU).

With regard to the set of independent variables, to study the influence of the structural characteristics and the role of knowledge activities, we have included some economic variables, such as the regional GDP per capita (GDP) and the region's employment specialization, measured as the percentage of total employment in high- and medium high-technology manufacturing sectors (HTEM), employment in total knowledge-intensive services (KISE), share of service employment over total (Service), and the economic activity rate (EconActiv). These economic variables have shown a positive impact for ICT adoption at the regional level in the EU (Billon et al., 2008; Milecevic & Gareis, 2003; Vicente & Lopez, 2006, 2011). In addition, we have included as an explanatory variable the total intramural R&D expenditure (TotRD). According to the literature, R&D expenditures stimulate ICT diffusion (Cohen & Levinthal, 1989) as some empirical papers have shown for the European regions (Martinelli et al., 2006; Schleife, 2010; Tranos & Gillespie, 2009; Vicente & Lopez, 2006, 2011).

Several theoretical models (Benhabib & Spiegel, 2005; Nelson & Phelps, 1966) have demonstrated the importance of human capital in the adoption and use of new technologies. Diffusion theory also states that individuals with higher educational levels tend to be more inclined to accept the risks and uncertainty associated with innovations, and to adopt them faster than people with lower levels of education (Rogers, 2003). Education provides the skills required for using and taking advantage of ICT. At the firm level, for instance, evidence has shown that a skilled labor force is able to use the Internet and other ICTs more efficiently (Kottemann & Boyer-Wright, 2009).

To capture the influence of human capital endowment, we have introduced lifelong learning (LifeLong), together with tertiary education (PopTer). A positive influence from educational attainment on ICT use is to be expected, as Schleife (2010) has shown with regard to Internet use in German regions. Nevertheless, the results are more ambiguous for other geographical areas (Hargittai, 1999; Kiiski & Pohjola, 2002), and in some cases depend on the type of technology and educational level (Quibria et al., 2003).

As already mentioned, technology diffusion occurs through the spreading of knowledge about the new technology to an increasing number of users through previous users. The demographic structure and ICT user characteristics play a key role in explaining ICT use and diffusion (Schleife, 2010). To examine their effects, we employ population age between 25 and 64 years (PopAge), population density (PopDen), and the percentage of the population living in densely populated areas (Urban). The empirical evidence available shows that younger European people are more likely than older people to use ICT (Lera-Lopez, Billon, & Gil, 2010; Schleife, 2010), but also that there are differences between ICT use at home and at work depending on age (OECD, 2013). The inclusion of population density and the urban population is justified as a measure of the possible influence of differences between rural and urban areas due to knowledge spillovers and network effects for ICT use. Different studies have highlighted the positive impact of these variables in promoting ICT use by European firms (Domenech et al., 2014; Galliano & Roux, 2008; Galliano et al., 2011), although the evidence is less clear explaining ICT at the household level, positive effects being found in some studies (Billon et al., 2008, 2009) but not in others (Schleife, 2010; Vicente & Lopez, 2011). In addition, we have incorporated a binary variable (Capital), which distinguishes those European regions that include a country's capital from those that do not. With this variable, we aim also to capture the possible influence of knowledge and information spillovers concerning ICT use that take place in major cities.

For institutional factors, we have employed two different variables: the quality of government (GQ) and the decentralization index (DC). The first variable measures the quality of the regional government across three general public services (education, health care, and law enforcement), as well as the presence of low levels of corruption or protection of the rule of law (Charron, Dykstra, & Lapuente, 2010, 2014; European Commission, 2010b). This variable is obtained from a survey of 34,000 European citizens, which constitutes the largest multi-country survey on the quality of government at the regional level (Sleuwaegen & Boiardi, 2014). Some empirical studies have shown a positive relationship between this variable and the Internet and computers (European Commission, 2010b). The DC variable measures the level of decentralization in each European country across five dimensions: financial, vertical, political, functional, and administrative, with special emphasis on fiscal decentralization via expenditures (Klipp, 2009). The regions that have more of these competencies tend generally to be in decentralized countries and have higher index values.

Table 1 includes the main descriptive statistics, sources, and descriptions for each of the variables. The database includes data from the 98 European regions within the EU-28. The regions correspond to the first level of disaggregation defined by Eurostat, according to the *Nomenclature d´Unité Territoriales Statistiques* (NUTS1). The year 2010 is the time reference for all variables. Due to its recent inclusion, Croatia is included in the database although the country was not an EU member in 2010. The selection of the NUTS1 as the level of disaggregation is due to the unavailability of data on ICT use at the firm level at the more disaggregated level, NUTS2.

The data employed in our analysis are taken from two different datasets. The variables for ICT use at the firm level have been obtained primarily from the Fifth European Working Conditions Survey, conducted by the European Foundation for the Improvement of Living and Working Conditions (Eurofund, 2012). The survey provides comparative information on the condition of work of employees in the EU-28. Also, the survey collects information about the use of computers and the Internet by workers within firms, and it has been used to measure ICT use by European firms (Martin & Omrani, 2015). The interviews were conducted face-to-face with a sample of more than 40,000 interviews.

The variables measuring ICT use at the household level are taken from the database of regional statistics in Europe (Eurostat, 2014). Economic, educational, and demographic variables are drawn from the same dataset. Institutional variables are taken from the European Commission (2010b) and Müller (2009).

Table 1. Variables, main descriptive statistics, and sources

	Variable	N	Minimum	Maximum	Mean	Median	St. Dev.	Description
ICT Household	**IU**	98	32.00	93.00	65.20	69.00	15.85	Individuals regularly using the Internet (percentage of individuals)
	PC	98	43.00	100.00	77.46	82.00	14.46	Individuals who have used a computer (percentage of individuals)
	EC	98	3.00	75.00	40.18	41.00	22.26	Individuals who ordered goods or services over the Internet, for private use, in the last year (percentage of individuals)
ICT Firm	**ERPC**	96	8.50	58.97	32.85	33.54	10.24	Employees regularly using a computer at work (percentage of individuals)
	ERIU	96	6.53	56.41	24.95	24.22	9.67	Employees regularly using Internet at work (percentage of individuals)
Econ.	**TotRD**	98	0.16	4.95	1.60	1.42	1.02	Total intramural R&D expenditure (GERD) by sectors of performance and region, as percentage of GDP
	GDP	98	3500.00	77400.00	24151.02	23900.00	12516.44	Gross domestic product (GDP) at current market prices. Purchasing power parity per inhabitant in percentage of the EU average
	HTEM	94	1.10	23.31	7.40	6.55	4.35	Annual data on employment in high- and medium high-technology manufacturing sector (percentage of total employment)
	KISE	97	18.00	61.80	40.35	40.60	8.50	Annual data on employment in total knowledge-intensive services: NACE Rev. 1.1 codes 61, 62, 64 to 67, 70 to 74, 80, 85, and 92 (percentage of total employment)
	Service	98	34.49	88.85	70.19	71.53	10.35	Percentage of service employment in total employment
	EconActiv	98	50.00	81.20	71.40	71.85	6.17	Economic activity rate: working+unemployed/total population (65 years). AGE from 15 to 64 years
Edu.	**LifeLong**	97	0.70	32.50	9.58	7.30	6.81	Life-long learning: participation of adults aged 25–64 in education and training (1000) (in percentage)
	PopTer	97	9.90	45.60	2634	27.40	8.04	Population aged 25–64 with tertiary education (in percentage)
Demo.	**PopAge**	98	63.24	72.44	67.18	66.79	2.21	Population at January 1 by sex and age. Aged 15–64 years (percentage)
	PopDen	98	5.90	6902.00	402.88	135.60	957.57	Population density (inhabitants per km^2)
	Urban	97	11.27	100.00	48.48	45.29	21.23	Percentage of household living in densely populated areas
Inst.	**GQ**	97	-2.37	1.62	0.23	0.51	0.95	Quality of government in EU
	FisDec	98	1.33	45.94	25.82	25.63	11.03	Fiscal decentralization indicators: subnational government share of expenditure (% of total government expenditure)
	CAPITAL	97	0	1	0.28	0		Binary variable indicating if the country's capital is in the NUTS1 (1) or not (0)

Notes: Econ = Economic; Edu = Educational; Demo = Demographic; Inst = Institutional. All data are taken from the Regional Statistics Dataset developed by Eurostat, except for the variables ERPC and ERIU derived from the 5th European Working Conditions Survey (Eurofund, 2012), GQ from an EU Commission Survey (European Commission, 2010a), and DC from BAK Basel Economics (Müller, 2009).

Source: Authors' own calculations.

4. Methodology

As we are interested in simultaneously investigating ICT use by households and firms, and we aim to determine possible patterns of ICT use, we have selected canonical correlation analysis (CCA) as the methodology to be applied. This methodology has some advantages compared to other linear and multiple regression techniques. First, employing CCA allows us to analyze ICT use combining different types of use, such as that of households and firms, without the need to reduce the phenomena studied to a single variable or a single synthetic indicator. Second, through the communality (correlations) in ICT use by households and firms, CCA analyzes the potential cross relationships between these types of ICT use that a separate multiple regression analysis would ignore.

In particular, CCA as a multivariate technique enables the assessment of the interrelationships between and across sets of multiple dependent and independent variables (Hair et al., 2010). Generally, CCA can be expressed as in equation (1), with $y_1, y_2, ..y_q$ as the set of variables for ICT use at household and firm levels and $x_1, x_2, \ldots x_p$ as the set of potential explanatory factors, previously described in section 3. CCA couples pairs of linear combinations of variables in each set, x^* and y^*, named canonical variates:

$$x^* = \boldsymbol{X\alpha} = \sum_{i=1}^{p} \alpha_i x_i \qquad y^* = \boldsymbol{Y\beta} = \sum_{j=1}^{q} \beta_j y_j \tag{4}$$

The CCA technique develops canonical functions that maximize the correlation coefficient between each pair of canonical variates, called the canonical correlation coefficient (ρ):

$$Corr(x^*, y^*) = \frac{E[\alpha' X' Y\beta]}{E[\alpha' X' X\alpha]^{1/2} E[\beta' Y' Y\beta]^{1/2}} = \rho \tag{5}$$

The model allows us to summarize the multidimensional relationship between the two sets of dependent and independent variables in a few dimensions: the canonical functions. The coefficient vector $\boldsymbol{\beta}$ defines a combination of interrelated variables in the dependent set that are highly explained by a combination of independent variables (defined by the coefficient vector $\boldsymbol{\alpha}$).

The first canonical function provides two canonical variates (x_1^*, y_1^*), with coefficient vectors $\boldsymbol{\alpha}_1$ and $\boldsymbol{\beta}_1$, are optimally calculated to maximize the correlation in equation (5). The second canonical function produces two canonical variates (x_2^*, y_2^*), with coefficient vectors $\boldsymbol{\alpha}_2$ and $\boldsymbol{\beta}_2$, optimally calculated to maximize the correlation in equation (5) and to be orthogonal to the first canonical variate pair, and so on. Because each canonical function is independent of the others, "they represent different relationships found among the sets of dependent and independent variables" (Hair et al., 2010, p. 237). The maximum number of canonical functions that can be extracted equals the number of variables in the smallest set, but those relevant for interpreting the CCA model are the canonical functions with practical significance.

5. Empirical analysis

We run the CCA to test these potential relationships and the differences between the *X* and *Y* sets. Table 2 shows the multivariate statistics testing the overall model fit. The null hypothesis (the two sets of variables are not linearly related) is rejected at α level 0.01. Before interpreting model results, we need to determine the number of significant dimensions. The canonical correlation coefficients measure the strength of the relationship between the two canonical variates. The first three coefficients are greater than 0.50, the value required for practical significance according to Hair et al. (2010). The sequential Chi-square statistical test rejects the null hypothesis in the first three tests, indicating three separate statistically significant canonical functions (Table 2).

However, as noted by several authors, including Johnson and Wichern (2007) and Hair et al. (2010), the selection of the canonical function should be based not only on tests of statistical significance, but also on redundancy analysis. This analysis allows us to examine the practical significance of the canonical functions. Therefore, to identify the significant dimensions, we calculate the Stewart–Love redundancy indices.

Table 2. Canonical correlation analysis

Measure of overall model fit			
Multivariate test	*Statistic*	*df*	*p-value*
Wilks´ lambda	.017	70	.000

Canonical Correlation Test				***Canonical Redundancy Analysis***		
Canonical function	*Canonical correlation*	*Sequential Chi-sq test*	*p-value*	*Squared correlation*	*Variance extracted in set Y*	*Redundancy Index y^*_i/x^*_i*
1	.950	335.500	.000	.903	.668	.603
2	.759	144.080	.000	.576	.194	.112
3	.662	73.589	.000	.438	.046	.020
4	.457	26.224	.242	.209	.043	.009
5	.286	6.975	.728	.082	.049	.004
				Total Redundancy Index Y/X		.748

Source: author's own calculations

The total variance of the ICT use set explained by the set of independent variables is 74.8%. The explained variance is concentrated in the two first canonical functions (60.3% and 11.2%, respectively), whereas the subsequent functions can be ignored because of their low explanatory power (2% or less). Consequently, the first two canonical functions with practical significance are those relevant for the analysis and considered for the purposes of interpretation. These canonical functions represent separate patterns, independent relationships between the two sets of variables, and capture 71.5% of the information of the set of dependent variables.

The sign and magnitude of the canonical loadings and canonical standardized coefficients are usually applied to understand and interpret the canonical functions. Table 3 depicts this information. The canonical loadings show the correlation of the individual variables with their respective canonical variates, and assess the relative contribution of each variable to each canonical function (Hair et al., 2010).

Table 3. Canonical loadings

	First Canonical Function *Canonical correlation = .95*	**Second Canonical Function** *Canonical correlation = .76*
Set Y	***y*₁***	***y*₂***
IU	.928	.118
PC	.947	-.069
EC	.986	-.075
ERPC	.622	.605
ERIU	.471	.761
Set X	***x*₁***	***x*₂***
TotRD	.681	-.006
HTEM	.259	-.826
KISE	.891	.212
Service	.745	.354
EconActiv	.696	-.169
LifeLong	.716	.391
PopTer	.630	.371
GDP	.688	.212
PopAge	-.528	.099
PopDen	.211	.042
Urban	.346	.061
GQ	.925	-.043
FisDec	.411	-.379
Capital	-.130	.479

Source: author's own calculations

As noted in Table 2, the first canonical variate of the independent variables, x_1^*, explains 60.3% of the variability in the dependent set. Some interesting results can be found for the first canonical function, which shows the first dimension of analysis. All of the dependent variables (IU, PC, EC, ERPC, and ERIU) have a positive relationship with their variate, y_1^* (positive loadings), and thus the first dimension captures the main source of variability shared for the all five ICT use variables. The first canonical variate mostly captures ICT use at the household level (as indicated by the canonical loadings close to 1), but it also includes information concerning ICT use within firms (ERPC and ERIU, with canonical loadings of 0.622 and 0.471, respectively). Therefore, the first canonical function entirely explains ICT use by households and partially explains ICT use by firms. This means that this function shows the factors driving ICT use at the household level, and also those partially driving ICT use at the firm level.

The main variables that explain both uses are primarily GQ and KISE, the variables presenting the highest loadings (0.925 and 0.891, respectively). This canonical combination of ICT use is also positively explained, although to a lesser extent, by Service (0.745), LifeLong (0.716), EconActiv (0.696), GDP (0.688), TotRD (0.681), and PopTer (0.630), and negatively by PopAge (-0.528), which means the higher the percentage of individuals between the ages of 15 to 64 years, the less the ICT use.

The regions can be scored and sorted according to the first pair of canonical variates. Among the top 10 regions with high values of ICT use are the three Swedish regions, Denmark, four UK regions (London, the South East, West, and East of England), the West Netherlands region, and Luxembourg. Holding the opposite pattern, in the bottom 10 we find the four Romanian regions, three of the four Greek regions, one Polish region, and the south of Italy. As a whole, this dimension shows significant differences between northern countries, predominantly Sweden, Finland, Denmark, and the UK, and southern countries, in particular Italy, Portugal, and Spain. Also, considerable differences are registered between Western countries and the Eastern countries recently incorporated into the EU.

The second dimension captures information on ICT use that has not been captured by the first. As can be seen from the canonical loadings in the second canonical function, the y_2^* variate shows ICT use by firms that is unrelated to or not shared with ICT use by households (canonical loadings 0.605 and 0.761 for ERPC and ERIU respectively, and almost zero for the variables measuring ICT use at the household level).

The specific ICT use by firms, unrelated to household use, is essentially related to low levels of HTEM (loading -0.826). Other explanatory variables that have significant explanatory power are LifeLong, PopTer, and Service, with high levels (canonical loadings

0.391, 0.371, and 0.354, respectively), as well as the low degree of fiscal decentralization (-0.379) and the country's capital being located in the region (Capital).

In the same way, the regional scores are calculated with the second pair of canonical variates. The top 10 European regions in this second dimension are Luxembourg, four UK regions (London, Northern Ireland, the South East, and Scotland), one region of Sweden (Östra Sverige), Spain (Canarias), the Netherlands (West Nederland), Belgium (Bruxelles) and France (Île de France). At the bottom are seven German regions (Bayern, Rheinland-Pfalz, Mecklenburg-Vorpommern, Schleswig-Holstein, Baden-Württemberg, Bremen, and Thüringen), two Romanian regions, and the Hungarian region of Dunántúl. Comparing the spatial distribution of this dimension to the first, there is a lower level of disparities in ICT use between northern and southern countries on the one hand, and between eastern and western countries on the other. In particular, some eastern and southern regions show values of ICT use by firms that are significantly higher than the values of ICT use by households.

Comparing the main discriminant variables for both dimensions, we highlight several interesting results. First, ICT use by households and ICT use by firms are related, KISE and GQ being the relevant drivers common to both. Second, some determinants affect only one dimension, for example HTEM, Capital, and DC, which are factors that exclusively affect ICT use by the firm. Third, some independent variables, such as PopDen and Urban, are not relevant in explaining ICT use in the EU-28.

6. Discussion and conclusions

This paper provides empirical evidence of ICT diffusion in both households and firms for European regions of the EU-28. We investigate the existence of common or differentiated patterns of ICT use, capturing combinations of both types of use, for households and firms, and identifying the factors that explain them. To this end, we employ a multivariate framework and canonical correlation analysis.

Our findings point to the existence of two differentiated patterns of ICT use at the regional level. The first pattern primarily captures ICT use by households and partially ICT use by firms, showing some close linkages between both uses. This first pattern is largely explained by institutional factors, such as the quality of government, and by region-specific economic characteristics, such as total employment in knowledge-intensive services (KISE) and employment in the services sector (Service). This combination of ICT uses is also explained by GDP and regional economic activity. These factors highlight the relevance of the characteristics of the regions, and institutional and economic factors in explaining ICT use in Europe.

Educational variables (LifeLong and PopTer) seem to play a less important role in the first pattern, confirming the lack of consensus regarding educational variables in explaining ICT use (Hargittai, 1999; Kiiski & Pohjola, 2002). Logically, this result is mediated by the high average level of education in Europe compared to other geographical areas and by consideration of the type of technology under study. Specific highly advanced technologies in other geographical areas could be restricted drastically by the educational attainment of the population. Finally, among the demographic variables, only population age is statistically and negatively significant, confirming the role shown by Lera-Lopez et al. (2010) and Schleife (2010). Neither population density nor the proportion of the population that is urbanized contribute significantly to explaining this first dimension, confirming previous literature on the uncertainty of these variables. The results for the first pattern show the traditional digital divide between northern and southern regions on the one hand, and between western and eastern regions on the other.

The second pattern captures ICT use by firms unrelated to use by households. This pattern is negatively determined by employment in the high-technology manufacturing sector (HTEM) and positively determined by the participation of the services sector (Service), confirming the importance of the development of the service sector in contrast to the manufacturing sector in terms of explaining ICT use by firms, as emphasized in previous studies (Billon et al., 2009; Milecevic & Gareis, 2003). In addition, this pattern is also explained by some educational variables, such as life-long learning (LifeLong) and the level of the population with a tertiary education (PopTer). Two institutional variables are of particular relevance: the decentralization index, with a negative influence, and the positive impact of the country's capital city. In particular, our findings highlight the relevance of knowledge and information spillovers associated with this last variable. The results also show that in the second dimension the traditional digital divide between northern and southern regions and eastern and western regions is less apparent.

We have found that ICT use by firms and households in European regions share explanatory factors, showing that there might be some synergies in the relation between both dimensions that should be considered when designing public policy geared toward encouraging ICT diffusion. In relation to this, our study highlights the relevance of and need for the development of a knowledge economy and service sector, together with high quality regional government, to boost simultaneously a greater use of ICT by firms and households at the regional level in the EU. In addition, any improvement in the quality of regional government would have positive and significant impacts on fostering the use of ICT by firms and households.

Our findings also show that in those regions with low levels of ICT use by households and firms, mainly situated in the southern and eastern parts of Europe, public policy could be used to improve the quality of regional government and implement initiatives that promote changes in the production structure. Such changes would stimulate employment the knowledge activities in the service sector. In less advanced regions (in terms of the first pattern) the implementation of initiatives guaranteeing lifelong learning opportunities should be considered, in particular focused on areas connected to the knowledge economy, together with traditional measures to increase GDP and employment.

Furthermore, our results related to the second pattern point to the importance of policies that might guarantee wider access to higher education and lifelong learning that may help to engender more transformative ICT use by firms in the European regions.

This study has some limitations that represent avenues for future research. The main limitations are related to the lack of data at the regional level for the European regions. This study did not allow us to include variables impacting the supply side of ICT use, such as ICT costs, telecommunications infrastructure, and market structure. Also, it was not possible to include other variables at the regional level that could explain ICT use within firms, such as firm structure, the adoption of high performance work practices, etc. Further research should be undertaken to analyze the effects of other potential variables, and to investigate whether the relationships between ICT use by households and firms may vary across different time periods. In addition, the study of spatial dependence among the European regions in ICT diffusion would allow us to examine neighboring effects.

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