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Determinants of ICT adoption: Evidence from firm-level data*

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Abstract

We analyse factors driving inter-firm and intra-firm diffusion of ICT using data from Irish manufacturing firms over the period 2001-2004. We find that the path of ICT diffusion has been uneven across firms, industries and space which is consistent with the theory of new technology adoption. Our research results suggest that firms which are larger, younger, fast-growing, skills-intensive, export-intensive and firms located in the capital city region have been relatively more successful in adopting and using ICT. We find positive technology spillovers from firms that have adopted ICT located in the same industry and region. To a certain extent, patterns of ICT adoption are different for domestic and foreign-owned firms, in particular with respect to the effects of exposure to foreign markets and firm size.

Key words: ICT diffusion, Human capital, Industrial structure, Technology spillovers.

JEL classification: L21, O31, O33

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1 Introduction

Information and Communication Technologies (ICT) are at the core of the "new" knowledge-based economy. There is growing evidence suggesting that ICT-linked knowledge, innovation and ongoing technological change are strong determinants of productivity, growth differentials as well as the ability of countries to benefit from globalisation (Jorgenson and Stiroh, 2000; Oliner and Sichel, 2000; Bassanini and Scarpetta, 2002; OECD, 2004; Timmer and van Ark, 2005).

The impact of ICT investment on productivity and growth is found to be greater at firm-level in comparison to industry and country-levels (Brynjolfsson and Hitt, 2000, 2003; Lehr and Lichtenberg, 1999; Matteucci et al., 2005). At the firm level, ICT use leads to improvements in product design, marketing, production, finance and the organisation of firms (Hollenstein, 2004). Furthermore, ICT is an innovation driver through facilitating the creation of new products and services (Becchetti et al., 2003; Carlsson, 2004; Hollenstein, 2004). ICT use increases the productivity of R&D activities in downstream sectors, so ICT use is the source of "innovation complementarities" (Bresnahan and Trajtenberg, 1995).

The focus of this paper is on the adoption of ICT at firm level. We distinguish between *inter-firm* adoption and *intra-firm* diffusion of ICT. Specifically, the question we investigate in this paper is: what factors affect the chances of adoption and diffusion of ICT at the firm level? We use a novel data set including survey information on e-commerce and ICT in Irish manufacturing firms and examine the impact of firm characteristics (rank effects) and spillover effects from proximity to ICT adopters (epidemic learning effects) as suggested by the existing theoretical and empirical literature on new technology diffusion.

Uncovering the factors driving ICT adoption and diffusion is important and relevant for both research and policy. First, in contrast with a well established theoretical literature on new technology adoption and diffusion, firm-level empirical evidence on ICT adoption and diffusion is still limited. Second, from the policy perspective, to the extent that a wide and fast diffusion of ICT is desirable, it is essential to understand what factors are likely to increase the adoption and diffusion of ICT.

This paper contributes to the empirical literature on determinants of new technology diffusion. Specifically, in comparison to existing cross-section studies, we estimate an improved econometric model by using a novel panel data and account for firm heterogeneity, industry, region and time specific effects which reduces the omitted variables bias. Our results show that the path of ICT diffusion across firms, industries and regions has been uneven which is consistent with the theory of new technology diffusion. We find empirical evidence which supports the hypothesised rank and epidemic learning effects.

The remainder of this paper is structured as follows. In Section 2 we discuss the related theoretical and empirical literature and testable hypotheses about the factors driving ICT adoption at firm level. In Section 3, we describe our data set, the ICT indicators and explanatory variables that we use in our empirical analysis. Section 4 outlines our empirical strategy and model specifications and in Section 5 we discuss our main results. Finally, we summarise our findings and conclude in Section 6.

2 Theoretical and Empirical Background

The theoretical starting point for our analysis is the well-established literature on new technology diffusion[1]. The main outcome of the new technology diffusion models is that the preferred adoption dates vary across potential adopters of a new technology. To understand the adoption and diffusion of ICT as a new technology it is therefore essential to uncover the factors that explain the variation in the rates of its adoption across firms, industries, regions and countries.

The early models of new technology diffusion known as *epidemic models* (Mansfield, 1963a,b, 1968) assumed that the adoption of a new technology depends on the spread of information about its availability or other "epidemic-type" learning factors. Information spreading or epidemic learning help to reduce the uncertainty related to new technologies. The learning effects are assumed exogenous and the diffusion path is driven by the reduction in the cost or improvement in the quality of the new technology (Stoneman, 2002). At any point in time only a number of potential adopters would wish to use, or would be sufficiently informed to use the new technology. The epidemic models predict that the adoption of new technology increases over time as the risk to adoption decreases due to learning effects across and within firms (Battisti and Stoneman, 2005).

Another group of theoretical models link the variation in the preferred adoption date to differentials in returns (profitability) to potential adopters from adopting the new technology. *Rank (or probit) models* (David, 1969; Davies, 1979; Ireland and Stoneman, 1986) point to firm heterogeneity as a driving factor behind differentials in gross returns from using the new technology and the variation in the preferred adoption dates. Thus firms with high returns from the adoption of new technology will be early adopters while firms with low returns from adoption will be late adopters. *Stock models* assume that the

[1] Karshenas and Stoneman (1993), Geroski (2000) and Stoneman (2002) provide excellent surveys of new technology diffusion models.

benefit to the marginal adopter from acquiring a new technology decreases with the increase in the number of previous adopters. Thus for any cost of acquiring the new technology, the adoption will not be profitable beyond a certain number of adopters. The adoption of a new technology is modelled as a strategic decision using a game-theoretic approach (Reinganum, 1981). *Order models* (Ireland and Stoneman, 1985; Fudenberg and Tirole, 1985) assume that the return to a firm from adopting a new technology depends upon its position in the order of adoption: the high-order adopters achieve a greater return than low-order adopters. Furthermore the decision of high-order adopters can affect the adoption date of low-order adopters. It follows that the firm's decision to adopt a new technology takes into account how waiting will affect its profits.

The theoretical literature also distinguishes between *inter-firm diffusion* – the diffusion path of the number of firms using the new technology, and *intra-firm diffusion* – the intensity of using the new technology by individual firms (Stoneman, 2002; Battisti and Stoneman, 2005). In the case of inter-firm diffusion, the adoption decision leads to a revenue externality while in the case of intra-firm diffusion, revenue externalities are internalised and appear in the marginal revenue from the adoption of new technology (Stoneman, 2002).

The bulk of existing empirical studies on determinants of new technology diffusion have focused on inter-firm diffusion while intra-firm diffusion has been less investigated (Battisti and Stoneman, 2005). Empirical evidence suggests that inter-firm diffusion appears more important in the earlier stages of adoption while intra-firm diffusion becomes more important later in the diffusion process (Battisti and Stoneman, 2003). While a large number of empirical studies have focused on a single model of new technology diffusion, models capturing all main effects- rank, stock, order and epidemic effects have been also estimated.

Rank effects have been modelled by using variables related to firm characteristics, such as sectoral specialisation, firm size, skill composition of the work force, and organisational structure. Helpman and Trajtenberg (1998) analyse the adoption of General-Purpose Technology (GPT) and point to sectoral specialisation as an explanatory factor. They show that GPT adoption is quicker when productivity growth is high with respect to the old technology. To the extent that ICT fosters productivity growth, this suggests that ICT adoption may be faster in ICT intensive industries relative to the rest of industries. Several empirical studies support this hypothesis. Love et al., (2005) show that the level of investment in information technology differs across industries. Cheung and Huang (2002) find evidence of major differences in the usage of the Internet across industries in Singapore.

Another stylised fact supported by a large empirical literature is that larger firms are more likely to adopt new technologies faster. Firm size is commonly used in the empirical literature on new technology adoption because it is easy to observe and it serves as a proxy for several things (Geroski, 2000): large firms can earn higher profits from adopting new technology in comparison to small firms. Given the risks and costs of early adoption they are in a better position to adopt new technology because they have fewer financial constraints and because they are likely to be less risk averse. They might be more motivated and able to innovate in order to pre-empt smaller rivals; also the scope for innovation complementarities is likely to be greater in larger firms. A positive correlation between firm size and ICT adoption is found in a number of empirical studies (Fabiani et al., 2005; Morgan et al., 2006; Teo and Tan, 1998; Thong, 1999). Other studies, in contrast, have found a weak or not significant relationship between firm size and the adoption of ICT (Lefebvre et al., 2005; Love et al., 2005; Teo et al., 1997). Furthermore, Hollenstein (2004) shows that this relationship might be non-linear. He finds that in the case of a sample of Swiss firms, firm size is positively related to early, and intensive use of

ICT[2] only in firms with up to 200 employees. He also finds that medium-sized companies use the Internet more intensively in comparison to large firms.

Following the seminal paper by Nelson and Phelps (1966), a large empirical literature has focused on the relationship between human capital and new technology adoption. Chun (2003) provides empirical evidence showing that highly educated workers are more likely to implement new technologies such as information technology. Bartel and Sicherman (1999) find that industries with higher rates of technological change require highly skilled workers. Caselli and Coleman (2001) find that educational attainment is an important determinant of the level of investment in computers in a sample of OECD countries over the period 1970-1990.

Firm-level evidence suggests that firms using advanced technology require high-skilled workers (Doms et al., 1997). Furthermore, the presence of high-skilled workers fosters innovation and facilitates ICT adoption and use at firm level (Arvanitis, 2005; Bayo-Moriones and Lera-López, 2007; Bresnahan et al., 2002, Fabiani et al., 2005; Falk, 2005; Lucchetti and Sterlacchini, 2004).

Another result in the empirical literature is that productivity gains are larger in firms that adopt ICT and change their internal organisation: For example, as shown by Caroli and van Reenen (2001), ICT adoption is associated with more horizontal structures, fewer hierarchical levels, a higher extent of team work and greater worker participation. Bresnahan et al. (2002) find that the use of information technologies is complementary to innovations in workplace organisation such as broader job responsibilities for line workers, more decentralised decision-making, and more self-managing teams. Further, information technology and new organisation models are complementary to worker skills. Black and Lynch (2001, 2004) find that firms in the US that improved their internal organisation to

[2] The intensity of ICT use is measured by two variables: the number of ICT elements adopted (digital assistants; laptop; PC, workstations, terminals; e-mail; Internet; EDI; LAN/WAN; Intranet; Extranet) and the share of employees using the Internet.

incorporate more high performance practices in conjunction with ICT experienced high productivity growth.

Competitive pressure has been identified as an incentive to innovate and adopt new technology (Porter, 1990; Gattignon and Robertson, 1989). Firms facing stronger competition are more inclined to innovate and adopt new technologies, such as ICT, in order to strengthen their performance and survival rate. Several studies show that competitive pressure is positively associated with ICT adoption (Dasgupta et al., 1999; Hollenstein, 2004; Kowtha and Choon, 2001). In contrast, other papers find no significant effect of competitive pressure on ICT adoption (Lee, 2004; Teo et al., 1997; Thong, 1999).

It has been argued that firms exposed to international competition in export markets are more inclined to innovate and adopt new technologies. Hollenstein (2004), Lucchetti and Sterlacchini (2004) and Bayo-Moriones and Lera-López (2007) find evidence showing that firms that export are more likely to use the Internet.

Epidemic effects affecting the adoption of new technologies are linked to characteristics of the environment in which firms operate such as firm density, information and knowledge spillovers, and network externalities. Given the uncertainty about the profitability of a new technology, observing the adoption decision of other firms might play an important role in the decision to adopt new technologies. It follows that information spillover effects from interactions among firms may be important for the adoption of ICT. Baptista (2000) finds that, in the case of a sample of firms from engineering and metalworking industries in the United Kingdom, proximity to early adopters of new technology is positively related to learning effects that fostered the adoption of new technology. Moreover, there is evidence suggesting that technology diffusion is geographically localised and information spillovers decline as distance between firms increases (Jaffe et al., 1993; Jaffe and Trajtenberg, 1999; Eaton and Kortum, 1999; Keller, 2002).

Another important aspect of the environment in which firms operate that is relevant for ICT adoption relates to the network nature of ICT. On the one hand, being part of a network increases the awareness of the new technology and reduces the risks associated with adopting and using it (Gourlay and Pentecost, 2002). In addition, network externalities are positively related to the number of users of the new technology (Oulton, 2002). On the other hand, the larger the number of firms, the more likely is the occurrence of coordination failures that can slow down the adoption rate (Cooper and John, 1988).

In relation to the role that networks play in the adoption of ICT it has been shown that given the increased need for co-ordination of activities, being part of a multinational increases the probability of adopting ICT. Galliano et al. (2001) show that multinational ownership is positively associated with ICT adoption. However, Teo and Ranganathan (2004) find no difference between foreign-owned and domestic plants with respect to the adoption of business-to-business (B2B) electronic commerce in Singapore.

Karshenas and Stoneman (1993) estimate an empirical model which captures simultaneously rank, stock, order and epidemic effects by using data on the diffusion of computer numerically controlled machine tools (CNC) in the UK engineering industry over the period 1968-1980. While their findings suggest the presence of rank and epidemic effects, there is little evidence of stock and order effects.

Our analysis relates to a few empirical studies investigating the ICT adoption at firm level. Fabiani et al. (2005) find that in Italian manufacturing, ICT adoption is positively associated with firm size, human capital, presence of large firms, and changes in organisational structures. Hollenstein (2004) looks at Swiss firms and finds similar results. In addition, he finds evidence for the positive effects on ICT adoption of information spillovers between firms and competitive pressure. Bayo-Moriones and Lera-López (2007) find that establishment size, multinational ownership and a highly-skilled workforce are positively associated with ICT adoption in a sample of Spanish firms. Furthermore, in their analysis quality control systems and team–based organisation or work are found to play an important role in ICT diffusion within firms.

3 Data

Our dataset is obtained by combining information from two sources. One data source is the 'Survey on E-Commerce and ICT' that has been conducted as part of an EU-wide effort to gain information on ICT use since 2002 on an annual basis by the Central Statistics Office (CSO). It targets a population of 8,000 enterprises in manufacturing and services. The principal variables collected refer to the level of Internet usage, types of connection to the Internet, reasons for using the Internet, sales and purchases via the Internet, and barriers to e-commerce. The second data source is the annual Census of Industrial Production that is also collected by the CSO. The census contains information on turnover, exports, purchases, acquisitions and sales of capital assets, indirect taxes, employment, earnings and other labour costs for all enterprises and local units with 3 or more employees.[3]

The two datasets can be merged through the establishment identifier at the enterprise level[4]. The merged dataset covers the period 2002-2004 for all variables. All information related to monetary information on transaction values over the Internet or electronic data interchange (EDI) in the Survey on E-Commerce and ICT is collected for the year prior to the survey year. As a result this information is available for the period 2001-2004. The match covers roughly 40 per cent of the enterprises in each year and is representative with respect to the size distribution, the industry classification and the regional distribution of manufacturing activity. In the 2004 data, smaller firms are to some extent underrepresented. As the sample for the e-commerce survey is re-drawn every year only a small fraction of the enterprises in the previous year's sample is covered in the following year.

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[3] The possibility for controlled access to anonymous micro data sets on the premises of the CSO is provided for in the Statistics Act 1993.

[4] In this paper we use the terms enterprise and firm interchangeably.

The final working sample includes firms in the core manufacturing industries.[5] Further, we checked the data for outliers. We define as outliers observations where wages per employee are in the top or bottom quarter percentile of the distribution. In addition, we define as outliers observations that have changes in labour productivity, output growth, wages per employee, the share of sales due to online transactions, the share of clerical workers and the share of managerial and technical workers in the top and bottom half percentiles of the distribution. We accumulate outliers and delete all firms that have one or more outliers according to this definition.

To measure ICT adoption, we construct the following four indicators:

Indicators of inter-firm ICT adoption:

- *web*: 1 if the firm has a website, 0 otherwise;
- *ns*: 1 if the firm accepts online transactions, 0 otherwise.

Indicators of intra-firm ICT diffusion:

- *empucomp*: the share of employees using a computer in the total number of employees;
- *esale*: the share of sales (turnover) due to online transactions – carried out via a website, email, and electronic data interchange (EDI).

The left half of Table 1 provides summary statistics related to our indicators of inter-firm ICT adoption, namely the existence of a website (*web*), and whether the company accepts online orders (*ns*). As shown in Table 1, by 2004, 60 per cent of firms had a website. The share of firms that have a website is higher for larger firms. The regional differences are not very large; the share of firms with a website is highest in the greater Dublin area. The share of firms having a website is 45 per cent for domestic firms and 72 per cent for foreign-owned firms. The share of firms that accept online orders has

[5] NACE Rev. 1.1 sectors 15-36. Sector 23 (Manufacture of coke, refined petroleum products and nuclear fuel) is excluded for reasons of confidentiality. We also exclude Sector 16 (Tobacco) as the small number of observations together with the homogeneity of observations leads to the exclusion of this sector in some regressions.

increased over the analysed period to just over 15 percent in the sample. The share of firms that accept or have received online orders is lowest in the group of firms that have between 250 and 499 employees; it is highest among the largest firms. The shares of firms that accept online orders do not differ much between domestic and foreign-owned firms. However, they differ substantially across the different NUTS3 regions, with the capital city region having the highest share of firms with online transactions.

Table 1: Indicators of inter-firm and intra-firm ICT diffusion: Summary statistics

	Indicators of inter-firm ICT adoption				Indicators of intra-firm ICT diffusion					
	Obs	% of firms with website	Obs	% of firms that accept orders online	Obs	% of employees using computers		Obs	% of turnover due to online transactions	
						Mean	StdDev		Mean	StdDev
Year										
2002	1,687	42.44	2,143	10.78	1,687	31.6	29.2	2,143	1.19	6.72
2003	2,169	47.44	1,636	14.06	2,050	33.9	29.6	1,636	1.83	8.71
2004	1,444	60.39	1,236	15.13	1,444	35.9	29.1	1,236	2.08	9.25
Size										
<20	2,922	36.82	2,572	12.33	2,871	30.8	29.5	2,572	1.44	7.35
20-49	1,235	56.84	1,253	13.73	1,202	33.3	27.8	1,253	1.19	5.11
50-249	933	70.53	946	13.64	905	39.2	28.9	946	2.13	9.90
250-499	135	84.44	154	10.39	131	52.0	28.9	154	3.71	16.59
500+	75	89.33	90	15.56	72	53.4	27.1	90	3.74	14.71
Ownership										
domestic	4,475	45.23	4,141	12.97	4,381	30.9	28.3	4,141	1.39	6.90
foreign	825	71.88	874	12.70	800	49.1	30.5	874	2.70	12.14
NUTS3 region										
border	726	46.97	670	12.54	709	25.5	24.9	670	2.22	9.80
midlands	308	44.81	289	9.34	302	26.0	22.6	289	0.72	4.25
west	476	50.21	436	15.14	469	34.5	30.0	436	1.35	6.39
dublin	1,370	54.01	1,259	17.55	1,331	42.6	32.7	1,259	1.86	7.45
mideast	538	49.26	539	12.24	530	33.0	28.3	539	1.80	9.44
midwest	443	48.53	449	11.80	432	33.3	29.2	449	1.26	5.23
southeast	692	44.80	687	8.73	680	28.6	26.0	687	1.19	8.44
southwest	747	49.40	686	10.35	728	33.6	28.7	686	1.67	9.38
Total	**5,300**	**49.38**	**5,015**	**12.92**	**5,181**	**33.7**	**29.4**	**5,015**	**1.62**	**8.08**

Note: The number of firms per year differs for the different indicators because all turnover related information is collected for the year prior to the year when the Survey on E-commerce and ICT was conducted (see Section 3 for more details on data from the Survey on E-commerce and ICT).

The right half of Table 1 provides summary statistics of the two indicators of intra-firm ICT diffusion, namely the share of employees using a computer (*empucomp*) and the share of sales transacted electronically (*esale*[6]) including both transactions over the Internet (website, email) as well as transactions via electronic data interchange (EDI). ICT use is higher in larger firms and there is a clear time trend over the three- or four-year period. Both the share of employees using computers and the share of turnover due to online transactions are higher in foreign-owned firms than in domestic firms: nearly 50 per cent of the employees in foreign-owned firms use a computer and 30 per cent in the domestic firms. The foreign-owned firms earn on average 2.7 per cent of their turnover with online sales compared to an average of 1.3 per cent among the domestic firms. Both indicators vary across regions with relatively more regional variation for the share of turnover due to online transactions.

4 Empirical Strategy and Model Specifications

To estimate inter-firm and intra-firm diffusion of ICT, we focus on the role of rank and epidemic effects suggested by the theory on new technology diffusion as discussed in Section 2. Given the fact that our data does not contain information on the initial dates of ICT adoption we are unable to identify stock and order effects.

We model the adoption of ICT in firm i, industry j, region r, at time t (Y_{ijrt}) as a function of rank effects (firm size, output growth, age, status, human capital, competitive pressure, industry concentration) and epidemic effects (spillover effects from adopters in the same industry and region, spillover effects from adopters in the same industry located in different regions). The basic model specification is as follows:

[6] Note that this variable is based mainly on the information from the E-Commerce survey. There is also a question on the share of turnover due to transactions over the Internet, EDI and email in the Census of Industrial Production. This information has been used to fill in missing years where possible and also for consistency checks between the two datasets.

$$Y_{ijrt} = \alpha + \beta_1 s_1 + \beta_2 s_2 + \beta_3 s_3 + \beta_4 s_4 + \beta_5 d \ln to_{ijrt} + \beta_6 age_{ijrt} + \beta_7 age^2_{ijrt} + \beta_8 multi_{ijrt}$$
$$+ \beta_9 \ln wpe_{ijrt} + \beta_{10} mantech_{ijrt} + \beta_{11} clerical_{ijrt} + \beta_{12} ex\text{int}_{ijrt} + \beta_{13} ex\text{int}^2_{ijrt} + \beta_{14} conc_{jrt} \quad (1)$$
$$+ \beta_{15} epid\_indreg_{jrt} + \beta_{16} epid\_ind_{jrt} + \lambda_j + \lambda_r + \lambda_t + \varepsilon_{ijrt}$$

Rank effects

We measure *firm size* using the number of employees and identify the following five size classes: firms with less than 20 employees (S_1), firms with 20-49 employees (S_2), firms with 50-249 employees (S_3), firms with 250-499 employees (S_4) and firms with 500 and more employees (S_5). s_1, s_2, s_3, s_4 are dummy variables for the size classes S_1, S_2, S_3 and S_4, respectively. In all regressions, the largest firms (S_5) are the reference group. Assuming that large firms are early adopters of ICT or use it more intensively, we expect negative coefficients for $\beta_1, \beta_2, \beta_3, \beta_4$.

Further rank effects include *output growth* (*dlnto*), *firm age* (*age*) and its square term (*age*^{2}) and a dummy variable which indicates whether a firm is a *multi-plant* firm (*multi)*. The inclusion of these variables is based on the prior that fast-growing firms, new firms or firms with outdated equipment are more likely to adopt new technologies or use them more intensively (Karshenas and Stoneman, 1993). While we expect to find $\beta_5 > 0$, the signs for β_6 and β_7 are ambiguous. This follows from the fact that while older firms may show higher rates of ICT adoption and use due to learning effects, younger firms may be better placed to adopt recent available technologies (Barbosa and Faria, 2008). Multi-plant enterprises may be more likely to adopt ICT early as they can spread the cost over several entities and benefit from enhanced communication within the group.

As a proxy for *human capital* we use average wages per employee (*wpe)*. In addition, we control for the skill composition of employees by using the share of managerial and technical staff in all employees (*mantech)*, and the share of clerical staff, including sales representatives, in all employees (*clerical)*. We expect to find that the parameters $\beta_9, \beta_{10}, \beta_{11}$ are positive and significantly different from zero.

Export-intensity (*exint*) and its square term (*exint*^{2}) are included as measures of firm international competitiveness. While we expect ICT adoption and diffusion to be positively associated with export intensity, the square term is included to capture a possible non-linearity whereby competitive pressure from exposure to foreign markets is likely to increase less than proportionally beyond a certain level of export intensity. In addition to exposure to international markets, to proxy the effect of *competition* on the adoption and diffusion of ICT we add a measure of industry concentration ($conc_{jt}$), the Herfindahl-Hirschman index (*HHI*) calculated at the 3-digit industry level in the home market as follows:

$$conc_{jt} = \sum_{j} (s_{ijt})^2, \text{ where } s_{ijt} = \frac{to_{ijt}}{\sum_{i} to_{jt}}. \tag{2}$$

If the parameters $\beta_1 - \beta_{14}$ are significantly different from zero, the hypothesis of the presence of rank effects cannot be rejected.

Epidemic effects

As pointed out above, spillover effects from interactions between firms are likely to be important determinants of ICT adoption at firm level. Firms might benefit from technology spillovers (epidemic learning effects) only if they are located near other firms adopting ICT (i.e. within the same region) or if they are part of the same industry.

To estimate epidemic effects we use two variables: the share of ICT adopters in the same industry j and region r at time t ($epid\_indreg_{jrt}$) and the share of ICT adopters in the same industry j located in the rest of the regions ($\bar{r}$) at time t ($epid\_ind_{j\bar{r}t}$). The two variables are calculated as follows:

$$epid\_indreg_{jrt} = \frac{X^{a}_{jrt}}{X_{jrt}}, \tag{3}$$

where X^{a}_{jrt} denotes enterprises that are using ICT in industry *j*, region *r* at time *t* and X_{jrt} is the total number of enterprises inn industry *j,* region *r* at time *t*.

$$epid\_ind_{j\bar{r}t} = \frac{X^{a}_{jt} - X^{a}_{jrt}}{X_{jt} - X_{jrt}}. \qquad (4)$$

We calculate these epidemic (spillover) measures based on the number of firms that have a website (*epid_indreg_web* and *epid_ind_web*) when the dependent variables are whether the firm has a website (*web*) and the share of employees using computers (*empucomp*). In turn, they are based on the number of firms accepting electronic orders (*epid_indreg_ns* and *epid_ind_ns*) when the dependent variables are whether a firm accepts online orders (*ns*) and the share of turnover due to online transactions (*esale*).

We control for unobserved industry-, region- and time-specific effects: λ_j, λ_r, λ_t, respectively are dummy variables for 20 NACE 2-digit industries, 8 NUTS3 regions and the years in our panel. Definitions, sources and summary statistics of all variables are given in the Appendix.

We estimate equation (1) using a probit estimator when our dependent variables are the bivariate indicators of inter-firm ICT adoption as it is the case with *web* and *ns*. The estimates related to the discrete dependent variables are shown in Tables 2 and 3. We further estimate a bivariate probit model for *web* and *ns* assessing firms' propensities to both have a website and to accept online sales. The results for this regression are shown in Table 5.

In the case of intra-firm ICT adoption, the dependent variables are continuous (*empucomp, esale)* and they take values between 0 and 1. In this case, we estimate a fractional probit model following Papke and Wooldridge (1996). The estimates related to the intra-firm ICT adoption are shown in Tables 6 and 7. The fractional probit model is appropriate for this type of data as it overcomes many of the flaws associated with Tobit or OLS models when the dependent variable is continuous taking values between 0 and 1.

Papke and Wooldridge (1996) propose a non-linear function for estimating the expected values of dependent variables y_i conditional on a vector of covariates, x_i, as follows:

$$E(y_i|x_i) = G(x_i\beta) \tag{5}$$

where G is any cumulative distribution function and the betas are the true population parameters. They chose the following logistic distribution[7]:

$$E(y_i|x_i) = \frac{\exp(x_i\beta)}{1+\exp(x_i\beta)} \tag{6}$$

and suggest the use of the following Bernoulli log-likelihood function to obtain the quasi-maximum likelihood estimator, $\hat{\beta}$:

$$L_i(\beta) = y_i \log[G(x_i\beta)] + (1-y_i)\log[1-G(x_i\beta)] \tag{7}$$

In all our regressions the standard errors are adjusted for clustering at the firm level. It might be the case that for a number of explanatory variables the firm's decision on their level may not be exogenous to the firm's decision on ICT adoption or the intensity of ICT use. In order to reduce potential endogeneity, all regressors are lagged by one year. This is possible because the explanatory variables are based on the Census of Industrial Production which collects information for all firms with more than three employees in every year. In the case of the epidemic effects terms, we are able to use lags without losing a year of data for those epidemic effects based on the share of firms with a website, because the CIP also collects information on whether firms have a website or not since 1999. For those epidemic effects based on the number of firms that accept online orders we have information for 2001 as this relates to monetary information collected for the year before the Survey on E-commerce and ICT is conducted. Ideally we would also like to control for firm fixed effects, however the large panel variation in combination with a short time dimension does not make this an appealing option.[8]

[7] As our bivariate models are implemented with normal distributions we use a probit link function instead.
[8] Depending on the dependent variable we only observe 15-26% of firms in all time periods. This sample is far from representative and shows very little variation in ICT adoption.

It has been argued that foreign owned firms are more likely to be early adopters of new technology and that they are important channels of new technology diffusion (Narula and Zanfei, 2005; Barbosa and Faria, 2008). To capture the ownership effect on ICT adoption and diffusion, we estimate the models for all firms jointly, but also for domestic and foreign-owned firms separately.

5 Empirical Results

The estimates for whether firms have a website are shown in Table 2. The models presented in the first two columns are estimated for all firms jointly. The model shown in the second column includes epidemic effects. The third and fourth column present results for separate estimations for the domestic firms and the foreign-owned firms.

The results indicate that smaller firms, in particular firms with less than 50 employees are less likely to have a website in comparison to firms with 500 and more employees. This seems to be the case for the domestic firms only. Further, our results indicate that fast-growing and younger firms are more likely to have a website. The human capital and employee composition variables (the average wage per employee, the share of managerial and technical employees and the share of clerical employees) have a positive effect on a firm's probability to have a website. For the foreign firms, only the average wage per employee has a significant effect on the probability of having a website. Exposure to competition on foreign markets as measured by the export intensity has a positive impact on the probability of a firm to have a website. It is also a case that beyond a certain level of export intensity the firms' probability to have a website increases less than proportionally as can be seen from the negative sign on the square term.

Table 2: Determinants of inter-firm ICT adoption: probit estimates of the propensity to have a website

	all firms no epid effects			all firms with epid effects			domestic firms			foreign firms		
rank effects												
s1(3-19)	-0.412	(0.113)	***	-0.376	(0.114)	***	-0.327	(0.173)	*	-0.278	(0.174)	
s2(20-49)	-0.277	(0.117)	**	-0.236	(0.119)	**	-0.180	(0.173)		-0.101	(0.140)	
s3(50-249)	-0.187	(0.122)		-0.154	(0.122)		-0.076	(0.181)		-0.079	(0.121)	
s4(250-499)	-0.077	(0.138)		-0.113	(0.135)		-0.059	(0.209)		-0.011	(0.130)	
dlnto	0.059	(0.026)	**	0.058	(0.027)	**	0.060	(0.028)	**	0.045	(0.064)	
age	-0.004	(0.002)	**	-0.004	(0.002)	**	-0.003	(0.002)		-0.010	(0.004)	***
age2	0.000	(0.000)	*	0.000	(0.000)	*	0.000	(0.000)		0.000	(0.000)	***
multi	0.085	(0.072)		0.067	(0.072)		0.076	(0.081)		0.076	(0.088)	
lnwpe	0.164	(0.033)	***	0.160	(0.033)	***	0.140	(0.035)	***	0.266	(0.099)	***
mantech	0.409	(0.095)	***	0.355	(0.096)	***	0.387	(0.105)	***	0.234	(0.176)	
clerical	0.597	(0.089)	***	0.498	(0.091)	***	0.484	(0.095)	***	0.334	(0.216)	
exint	1.113	(0.140)	***	0.993	(0.143)	***	0.957	(0.157)	***	0.770	(0.355)	**
exint2	-1.052	(0.146)	***	-0.972	(0.149)	***	-0.903	(0.174)	***	-0.733	(0.316)	**
conc	0.252	(0.130)	*	0.047	(0.145)		-0.030	(0.167)		0.299	(0.255)	
epidemic effects												
epid_indreg_web				0.710	(0.064)	***	0.734	(0.074)	***	0.466	(0.106)	***
epid_ind_web				-0.127	(0.102)		-0.117	(0.111)		-0.443	(0.216)	**
controls												
border	-0.013	(0.038)		0.035	(0.038)		0.015	(0.042)		0.118	(0.064)	*
midlands	-0.037	(0.053)		0.009	(0.055)		-0.010	(0.058)		0.137	(0.072)	*
west	0.027	(0.042)		0.059	(0.042)		0.048	(0.045)		0.110	(0.070)	
mideast	-0.029	(0.042)		0.006	(0.042)		-0.011	(0.045)		0.117	(0.069)	*
midwest	-0.013	(0.045)		0.028	(0.045)		0.035	(0.050)		0.027	(0.080)	
southeast	-0.039	(0.038)		0.001	(0.038)		-0.016	(0.041)		0.111	(0.062)	*
southwest	0.015	(0.038)		0.016	(0.038)		0.035	(0.041)		-0.028	(0.079)	
2003	0.057	(0.012)	***	0.037	(0.012)	***	0.041	(0.013)	***	0.016	(0.026)	
2004	0.133	(0.016)	***	0.105	(0.018)	***	0.109	(0.020)	***	0.079	(0.037)	**
Ind χ^2[p]	47.57	[0.00]		32.37	[0.03]		28.10	[0.08]		18.88	[0.40]	
Obs/Firms	4859	2625		4859	2625		4098	2234		749	394	
LogL	-2808.8			-2695.7			-2310.7			-350.0		
χ^2	595.9			656.8			530.6			94.5		
R^2 pseudo	0.17			0.20			0.18			0.21		

Marginal effects and standard errors in parenthesis. ***, **, * indicate significance at 1%, 5%, 10%, respectively. All explanatory variables are lagged by one year with respect to the dependent variable. Omitted categories are: size: S_5 (500+), region: Dublin, year: 2002. Ind χ^2 [p] - χ^2 test for the joint significance of the non-reported NACE 2-digit industry dummies [p-value]. Industry-year-cells with only one firm are not included.

There is no evidence of geographic (location) effects on the probability of having a website, except at the margin for the foreign-owned firms where being located in some regions outside Dublin has a positive impact on a firm's probability to have a website. The time dummies are significant indicating a positive time trend in the adoption of websites. The industry dummies are jointly significant except for the foreign-owned firms. When we include the epidemic effects, we find that when firms are located in the same industry and region with a large share of other firms that have a website they are also more likely to have a website. For the foreign-owned firms there seems to be a negative compensating effect from being in the same industry but not in the same region with a large share of firms that have website.

Table 3: Determinants of inter-firm ICT adoption: probit estimates of the propensity to accept online orders

	all firms no epid effects			all firms with epid effects			domestic firms			foreign firms		
rank effects												
s1(3-19)	0.023	(0.056)		0.038	(0.051)		-0.039	(0.081)		0.155	(0.156)	
s2(20-49)	0.014	(0.056)		0.032	(0.054)		-0.037	(0.069)		0.073	(0.098)	
s3(50-249)	0.002	(0.053)		0.018	(0.051)		-0.047	(0.060)		0.088	(0.079)	
s4(250-499)	-0.028	(0.055)		-0.019	(0.054)		-0.085	(0.035)	**	0.077	(0.124)	
dlnto	0.017	(0.017)		0.015	(0.017)		0.021	(0.020)		0.012	(0.027)	
lnwpe	-0.001	(0.019)		0.002	(0.019)		0.005	(0.020)		-0.030	(0.052)	
mantech	0.069	(0.050)		0.058	(0.048)		0.027	(0.058)		0.136	(0.089)	
clerical	0.087	(0.044)	**	0.068	(0.043)		0.046	(0.047)		0.290	(0.100)	***
age	-0.001	(0.001)		-0.001	(0.001)		-0.002	(0.001)	*	0.001	(0.002)	
age2	0.000	(0.000)	**	0.000	(0.000)	*	0.000	(0.000)	**	0.000	(0.000)	
exint	0.324	(0.079)	***	0.278	(0.075)	***	0.316	(0.085)	***	0.031	(0.181)	
exint2	-0.274	(0.079)	***	-0.239	(0.077)	***	-0.274	(0.094)	***	-0.007	(0.161)	
conc	0.007	(0.081)		-0.026	(0.077)		-0.040	(0.089)		-0.021	(0.120)	
multi	0.025	(0.040)		0.033	(0.041)		0.009	(0.039)		0.093	(0.122)	
epidemic effects												
epid_indreg_ns				0.275	(0.038)	***	0.248	(0.042)	***	0.309	(0.085)	***
epid_ind_ns				0.109	(0.072)		0.151	(0.084)	*	-0.092	(0.119)	
controls												
border	-0.045	(0.017)	**	-0.038	(0.017)	**	-0.053	(0.017)	***	0.060	(0.065)	
midlands	-0.073	(0.017)	***	-0.060	(0.018)	***	-0.063	(0.019)	***	-0.026	(0.057)	
west	-0.020	(0.022)		-0.016	(0.021)		-0.003	(0.025)		-0.072	(0.025)	***
mideast	-0.044	(0.019)	**	-0.038	(0.019)	**	-0.035	(0.022)		-0.017	(0.044)	
midwest	-0.040	(0.020)	**	-0.029	(0.021)		-0.045	(0.022)	**	0.074	(0.062)	
southeast	-0.066	(0.016)	***	-0.056	(0.016)	***	-0.054	(0.018)	***	-0.047	(0.039)	
southwest	-0.057	(0.016)	***	-0.050	(0.016)	***	-0.053	(0.017)	***	-0.009	(0.043)	
2003	0.036	(0.011)	***	0.035	(0.012)	***	0.037	(0.013)	***	0.039	(0.025)	
2004	0.049	(0.014)	***	0.031	(0.014)	**	0.039	(0.015)	**	0.007	(0.025)	
Ind χ^2[p]	42.29	[0.00]		15.66	[0.68]		11.07	[0.89]		28.26	[0.02]	
Obs/Firms	3993	2298		3993	2298		3319	1937		626	341	
LogL	-1464.3			-1433.0			-1193.5			-205.3		
χ^2	142.2			211.9			173.9			114.2		
R^2 pseudo	0.06			0.08			0.08			0.18		

Marginal effects and standard errors in parenthesis. ***, **, * indicate significance at 1%, 5%, 10%, respectively. All explanatory variables are lagged by one year with respect to the dependent variable. Omitted categories are: size: S_5 (500+), region: Dublin, year: 2002. Ind χ^2 [p] - χ^2 test for the joint significance of the non-reported NACE 2-digit industry dummies [p-value]. Industry-year-cells with only one firm are not included.

Table 3 shows the estimates for a firm's propensity to accept orders online. There is no evidence of size effects[9] or effects from other firm characteristics and even the composition of the work force does not matter much. An important driver is again exposure to competition on export markets, also with the inverse u-shaped relationship observed previously. The export intensity matters only for the domestic firms. There are two possible reasons for this which are not mutually exclusive. First, this result reflects the fact that virtually all foreign-owned firms are exporters, while the domestic firms have on average smaller export intensities and the share of non-exporters among them is also larger. To the extent that exporting is closely correlated with productivity,[10] this indicates that the more productive domestic plants are also more likely to accept online orders. Second, for the foreign-owned firms it is quite likely that the decision to implement an online ordering system is beyond their control because it is taken in their headquarters abroad.

There are significant location effects, in that firms that are located outside the capital city region are less likely to accept orders online, in particular the domestic firms. We observe a positive time trend except for the foreign-owned firms. The industry dummies are jointly significant when we do not include the epidemic effects and for the foreign-owned firms with the epidemic effects included. The epidemic effects here indicate that being in a region and industry where there is a large share of firms that accept online orders has a positive impact on a firm's propensity to accept online orders. For the domestic firms there is weak support that being in an industry with a large share of firms that accept online orders also has a positive impact.

We further examine to what extent firms use both a website and online orders. Table 4 shows the distribution of firms in four groups: firms using both a website and

[9] The negative significant coefficient on the group of domestic firms with 250-499 employees possibly reflects the fact that most firms in this group are in the food sector (NACE15) which has one of the lowest shares of firms accepting online orders.

[10] There is evidence that more productive firms are more likely to select into exporting both internationally (International Study Group on Exports and Productivity, 2007) as well as for Ireland (Ruane and Sutherland, 2004).

accepting online orders; firms accepting online orders but with no website (this is not a contradiction as online orders includes email and EDI); firms having a website but not accepting online orders; firms with neither online orders nor a website.

Table 4: The number of firms using a website and online orders

		firm accepts online orders		
		0	1	No. firms
firm has a website	0	1,303	104	1,407
	1	1,174	286	1,460
	No. firms	2,477	390	2,867

The sample size for this analysis is smaller in comparison to the previous two regressions because the observations for *web* and *ns* come from different years. As we can see more than half of the firms in the sample have a website but only about 13 per cent of firms accept or have received online orders and only about 10 per cent of the firms have both a website and accept online orders.

The estimates of the bivariate probit model are shown in Table 5. Firms with a large share of clerical employees, firms with higher export intensities, and firms located in the capital city region are more likely to have a website and to accept online orders. Being in the same industry and region where there is a high share of firms that have a website and in the same industry and region where there is a high share of firms that accept online orders has a positive impact on firms to do both: have a website and accept online orders. Firms with less than 20 employees are more likely to accept online orders without having a website than firms with 500 employees or more. The same is true for firms with a small share of managerial and technical staff. There are location effects: firms located in some areas outside the capital city region are less likely to accept online orders but not have website. There are positive epidemic effects from being in the same industry and region with a large share of firms that accept online orders, but negative spillover effects from being in an industry and region where a high share of firms have a website for a firm's propensity to accept online sales, but having no website.

Table 5: Determinants of inter-firm ICT adoption: bivariate probit estimates of website usage and online orders

	ns=1, web=1			ns=1, web=0			ns=0, web=1			ns=0, web=0		
rank effects												
s1(3-19)	0.004	(0.046)		0.048	(0.025)	*	-0.298	(0.120)	**	0.246	(0.133)	*
s2(20-49)	0.005	(0.048)		0.031	(0.029)		-0.162	(0.122)		0.127	(0.137)	
s3(50-249)	0.002	(0.047)		0.009	(0.023)		-0.053	(0.127)		0.042	(0.139)	
s4(250-499)	-0.016	(0.051)		-0.001	(0.029)		-0.030	(0.156)		0.047	(0.156)	
dlnto	0.013	(0.015)		0.002	(0.007)		0.014	(0.033)		-0.030	(0.035)	
age	-0.001	(0.001)		0.000	(0.000)		-0.003	(0.002)	*	0.004	(0.002)	**
age2	0.000	(0.000)		0.000	(0.000)		0.000	(0.000)		0.000	(0.000)	
multi	0.007	(0.039)		-0.010	(0.012)		0.099	(0.088)		-0.095	(0.090)	
lnwpe	0.021	(0.016)		-0.011	(0.007)		0.120	(0.037)	***	-0.131	(0.041)	***
mantech	0.033	(0.044)		-0.043	(0.021)	**	0.375	(0.116)	***	-0.365	(0.119)	***
clerical	0.093	(0.042)	**	-0.027	(0.019)		0.400	(0.104)	***	-0.466	(0.111)	***
exint	0.263	(0.068)	***	-0.013	(0.031)		0.685	(0.165)	***	-0.935	(0.174)	***
exint2	-0.229	(0.069)	***	0.019	(0.032)		-0.648	(0.168)	***	0.858	(0.177)	***
conc	-0.002	(0.071)		-0.021	(0.031)		0.140	(0.169)		-0.117	(0.187)	
epidemic effects												
epid_indreg_ns	0.242	(0.034)	***	0.109	(0.019)	***	-0.205	(0.087)	**	-0.146	(0.087)	*
epid_ind_ns	0.091	(0.064)		0.043	(0.031)		-0.093	(0.154)		-0.041	(0.159)	
epid_indreg_web	0.079	(0.032)	**	-0.061	(0.016)	***	0.602	(0.076)	***	-0.620	(0.078)	***
epid_ind_web	0.012	(0.052)		0.031	(0.023)		-0.189	(0.123)		0.145	(0.131)	
controls												
border	-0.017	(0.016)		-0.011	(0.006)	*	0.042	(0.043)		-0.015	(0.047)	
midlands	-0.064	(0.013)	***	-0.027	(0.005)	***	0.087	(0.069)		0.005	(0.070)	
west	-0.019	(0.018)		-0.011	(0.007)		0.037	(0.049)		-0.007	(0.052)	
mideast	-0.025	(0.017)		-0.011	(0.007)		0.021	(0.049)		0.015	(0.051)	
midwest	-0.006	(0.020)		-0.003	(0.009)		0.005	(0.055)		0.003	(0.057)	
southeast	-0.040	(0.014)	***	-0.016	(0.006)	***	0.015	(0.043)		0.041	(0.046)	
southwest	-0.034	(0.014)	**	-0.013	(0.006)	**	0.011	(0.046)		0.036	(0.047)	
2003	0.030	(0.010)	***	0.009	(0.005)	*	0.003	(0.016)		-0.042	(0.016)	***
2004	0.028	(0.013)	**	-0.001	(0.005)		0.064	(0.024)	***	-0.091	(0.024)	***
Ind χ^2[p]					52.54		[0.06]					
Obs/Firms					2867		1667					
LogL					-2576.3							
χ^2					627.5							

Marginal effects and standard errors in parenthesis. ***, **, * indicate significance at 1%, 5%, 10%, respectively. All explanatory variables are lagged by one year with respect to the dependent variable. Omitted categories are: size: S_5 (500+), region: Dublin, year: 2002. Ind χ^2 [p] - χ^2 test for the joint significance of the non-reported NACE 2-digit industry dummies [p-value]. Industry-year-cells with only one firm are not included.

For a firm's propensity to have a website but not to accept online orders, the determinants are very similar to the results in Table 2 where we assessed the propensity to have a website only. In the last column of Table 5 we can look at the determinants of not having a website and also not accepting online orders. Firms with less than 20 employees have a higher propensity to fall into this group than firms with 500 and more employees, and so do older firms. Firms with high human capital intensities are less likely to fall into this group, the same is true for firms with high export intensities (with an increasing propensity). The negative coefficients of both measures for epidemic effects and the suggest that this group of firms might be missing out on the ICT diffusion path.

Table 6: Determinants of intra-firm ICT diffusion: Fractional probit estimates for the share of employees using computers

	all firms no epid effects			all firms with epid effects			domestic firms			foreign firms		
rank effects												
s1(3-19)	-0.054	(0.037)		-0.038	(0.037)		0.005	(0.044)		-0.008	(0.073)	
s2(20-49)	-0.070	(0.034)	**	-0.053	(0.034)		-0.010	(0.044)		-0.060	(0.056)	
s3(50-249)	-0.062	(0.033)	*	-0.050	(0.033)		-0.024	(0.041)		-0.038	(0.051)	
s4(250-499)	0.000	(0.038)		-0.001	(0.038)		-0.032	(0.045)		-0.006	(0.052)	
dlnto	-0.011	(0.014)		-0.013	(0.014)		-0.011	(0.014)		-0.017	(0.041)	
age	-0.003	(0.001)	***	-0.003	(0.001)	***	-0.002	(0.001)	***	-0.003	(0.002)	
age2	0.000	(0.000)	***	0.000	(0.000)	***	0.000	(0.000)	***	0.000	(0.000)	
multi	0.002	(0.024)		-0.006	(0.023)		0.044	(0.029)		-0.083	(0.045)	*
lnwpe	0.129	(0.017)	***	0.127	(0.017)	***	0.109	(0.017)	***	0.209	(0.069)	***
mantech	0.418	(0.050)	***	0.382	(0.050)	***	0.321	(0.056)	***	0.562	(0.098)	***
clerical	0.557	(0.041)	***	0.490	(0.042)	***	0.458	(0.043)	***	0.582	(0.127)	***
exint	0.154	(0.061)	**	0.098	(0.061)		0.203	(0.065)	***	-0.258	(0.190)	
exint2	-0.069	(0.062)		-0.035	(0.062)		-0.208	(0.071)	***	0.266	(0.166)	
conc	0.121	(0.054)	**	-0.021	(0.057)		-0.010	(0.068)		-0.068	(0.133)	
epidemic effects												
epid_indreg_web				0.110	(0.027)	***	0.108	(0.029)	***	0.060	(0.065)	
epid_ind_web				0.284	(0.047)	***	0.275	(0.050)	***	0.216	(0.114)	*
controls												
border	-0.058	(0.016)	***	-0.052	(0.016)	***	-0.051	(0.016)	***	-0.042	(0.053)	
midlands	-0.047	(0.020)	**	-0.042	(0.020)	**	-0.032	(0.021)		-0.080	(0.052)	
west	0.008	(0.021)		0.010	(0.021)		0.014	(0.021)		0.012	(0.069)	
mideast	-0.022	(0.019)		-0.015	(0.019)		-0.016	(0.019)		-0.006	(0.061)	
midwest	-0.010	(0.020)		-0.012	(0.019)		-0.012	(0.020)		-0.020	(0.055)	
southeast	-0.042	(0.017)	**	-0.037	(0.017)	**	-0.026	(0.017)		-0.066	(0.052)	
southwest	-0.014	(0.016)		-0.020	(0.016)		-0.015	(0.017)		-0.030	(0.045)	
2003	0.014	(0.007)	**	0.002	(0.007)		0.008	(0.007)		-0.040	(0.021)	*
2004	0.007	(0.008)		-0.014	(0.008)	*	-0.006	(0.009)		-0.045	(0.023)	*
Ind χ^2[p]	249.89	[0.00]		171.46	[0.00]		166.07	[0.00]		39.79	[0.00]	
Obs/Firms	4742	2625		4742	2625		4006	2234		736	403	
LogL	-2047.8			-2030.9			-1674.9			-341.7		
χ^2	1353.1			1449.3			1005.8			484.7		

Marginal effects and standard errors in parenthesis. ***, **, * indicate significance at 1%, 5%, 10%, respectively. All explanatory variables are lagged by one year with respect to the dependent variable. Omitted categories are: size: S_5 (500+), region: Dublin, year: 2002. Ind χ^2 [p] - χ^2 test for the joint significance of the non-reported NACE 2-digit industry dummies [p-value]. Industry-year-cells with only one firm are not included.

We next analyse determinants of intra-firm ICT diffusion or the intensity of ICT use within firms. We start by examining the estimates of the share of employees using computers shown in Table 6. Firms that have between 20 and 249 employees are marginally less likely to have a high share of employees using computers than firms with 500 and more employees; however this result disappears when the epidemic effects are included. Younger firms are associated with higher shares of employees using computers. Not surprisingly, there are strong positive effects from the average wage per employee and from large shares of managerial and technical employees as well as from large shares of clerical employees. Again, only for the domestic firms a high export intensity is positively associated with the share of employees using computers. There are some location effects; also here some regions have a lower propensity to have a high share of employees using computers than firms located in the capital city region. There are positive effects from being in an industry and region where a high share of firms have a website and from being in the same industry but not the same region where a high share of firms have a website has a positive impact on the share of employees using computers. Here the industry effects are stronger than the industry-region effects; this is plausible when considering that some industries are much better suited for the use of computerised production processes than others.

Table 7 shows the estimates for our second measure of the intensity of ICT use, namely the share of turnover due to online transactions. In this case only a few determinants appear significant. There is some indication that smaller firms (having between 20 and 49 employees) are associated with smaller shares of turnover due to online transactions than the largest firms. Again export intensity or exposure to international competition has a positive impact for the domestic firms only. We find a significant negative effect from being part of a multi-unit enterprise on a firm's propensity to have a high share of turnover due to online transactions. This could reflect the fact that the largest shares of multi-unit enterprises are in NACE sectors 24 (Manufacture of chemicals, chemical products and man-made fibres) and 26 (Manufacture of other non-metallic mineral products), which have among the lowest shares of turnover due to online transactions. Also here there are positive epidemic effects from being in the same industry and region where a large share of firms accepts online orders. For the domestic firms there is also a positive industry epidemic effect. In all regressions the industry dummies are jointly significant, pointing towards industry affiliation as an indicator of the share of turnover due to online transactions.

Table 7: Determinants of intra-firm ICT diffusion: fractional probit estimates for the share of turnover due to online transactions

	all firms no epid effects			all firms with epid effects			domestic firms			foreign firms		
rank effects												
s1(3-19)	-0.012	(0.011)		-0.008	(0.009)		-0.008	(0.010)		0.002	(0.008)	
s2(20-49)	-0.014	(0.006)	**	-0.010	(0.005)	*	-0.009	(0.006)		-0.005	(0.003)	
s3(50-249)	-0.009	(0.006)		-0.006	(0.006)		-0.006	(0.005)		0.002	(0.005)	
s4(250-499)	-0.006	(0.007)		-0.005	(0.006)		-0.009	(0.001)	***	0.003	(0.008)	
dlnto	0.003	(0.004)		0.003	(0.004)		0.005	(0.005)		0.000	(0.002)	
age	0.000	(0.000)		0.000	(0.000)		0.000	(0.000)		0.000	(0.000)	
age2	0.000	(0.000)		0.000	(0.000)		0.000	(0.000)		0.000	(0.000)	
multi	-0.008	(0.003)	**	-0.007	(0.003)	***	-0.006	(0.002)	***	-0.003	(0.003)	
lnwpe	0.000	(0.004)		0.001	(0.003)		0.000	(0.003)		0.007	(0.005)	
mantech	0.016	(0.009)	*	0.013	(0.008)		0.002	(0.009)		0.012	(0.007)	
clerical	0.002	(0.007)		0.000	(0.007)		-0.005	(0.005)		0.015	(0.011)	
exint	0.037	(0.017)	**	0.025	(0.014)	*	0.037	(0.014)	***	-0.009	(0.012)	
exint2	-0.021	(0.017)		-0.013	(0.015)		-0.032	(0.015)	**	0.019	(0.012)	
conc	0.003	(0.017)		-0.003	(0.014)		0.003	(0.013)		-0.020	(0.011)	*
epidemic effects												
epid_indreg_ns				0.044	(0.007)	***	0.033	(0.008)	***	0.030	(0.008)	***
epid_ind_ns				0.011	(0.012)		0.025	(0.012)	**	-0.012	(0.010)	
controls												
border	0.002	(0.005)		0.004	(0.004)		0.001	(0.003)		0.023	(0.015)	
midlands	-0.006	(0.004)		-0.003	(0.004)		-0.004	(0.003)		0.011	(0.013)	
west	-0.003	(0.003)		-0.002	(0.003)		-0.001	(0.003)		0.004	(0.007)	
mideast	-0.003	(0.004)		-0.001	(0.003)		-0.003	(0.003)		0.012	(0.010)	
midwest	-0.005	(0.003)		-0.003	(0.003)		-0.003	(0.003)		0.006	(0.007)	
southeast	-0.004	(0.004)		-0.004	(0.003)		-0.003	(0.003)		0.005	(0.012)	
southwest	-0.002	(0.004)		-0.001	(0.004)		-0.001	(0.004)		0.005	(0.006)	
2003	0.006	(0.002)	***	0.006	(0.002)	***	0.005	(0.002)	***	0.004	(0.002)	*
2004	0.006	(0.002)	***	0.003	(0.002)		0.004	(0.002)	*	-0.001	(0.002)	
Ind χ^2[p]	36.96	[0.01]		33.00	[0.02]		219.93	[0.00]		1115.4	[0.00]	
Obs/Firms	3993	2298		3993	2298		3334	1946		659	360	
LogL	-278.5			-266.7			-198.1			-54.8		
χ^2	120.4			147.6			699.3			2170.5		

Marginal effects and standard errors in parenthesis. ***, **, * indicate significance at 1%, 5%, 10%, respectively. All explanatory variables are lagged by one year with respect to the dependent variable. Omitted categories are: size: S_5 (500+), region: Dublin, year: 2002. Ind χ^2 [p] - χ^2 test for the joint significance of the non-reported NACE 2-digit industry dummies [p-value]. Industry-year-cells with only one firm are not included.

Given the fact that the intensity of ICT diffusion depends on ICT adoption (Battisti and Stoneman 2005) the estimates of determinants of intra-firm ICT diffusion might reflect a sample selection bias. When the dependent variable is the share of employees using computers (*empucomp*) this is not an issue since by 2004, 96 per cent of all enterprises in the dataset use computers. To address this concern when the share of turnover due to online transactions is the dependent variable we also estimated a Heckman selection model where selection depends on whether a firm accepts online orders. We model the selection decision as a function of firm size, firm age, the multi-unit dummy, industry, region and time characteristics. However, the selection term does not turn out to be significant and the results for the share of turnover due to online transactions do not change qualitatively.[11]

6 Concluding Remarks

This paper contributes to the empirical analysis of determinants of new technology diffusion. In comparison to existing cross-section studies we estimate an improved econometric model using a novel firm-level panel data from the Irish manufacturing. In particular, we provide empirical evidence on factors driving the inter-firm ICT adoption (the usage of web sites, online orders) and intra-firm ICT diffusion (the share of employees using computers, the share of turnover due to online transactions). We find that the path of ICT diffusion has varied across firms, industries and regions which is consistent with the theory of new technology diffusion. Our results support the hypothesised rank and epidemic effects. In appears that the speed of ICT diffusion is influenced by firm characteristics such as firm size, age, skill intensity, exposure to foreign markets and proximity to early adopters of ICT in the same industry and regions.

Our main findings can be summarised as follows. The propensity to have a web site is higher for larger, younger, fast-growing, skill-intensive and export-intensive firms. Industry concentration in the domestic market does not appear to have a significant effect on the speed of ICT diffusion. In contrast to domestic firms, in the case of foreign-owned firms, size does not matter. The probability of having a website has increased over time

[11] Results are not reported but are available from the authors on request.

and it is positively associated with being located in the same industry and region. Further, we find that exposure to foreign markets is positively associated with the probability of accepting online orders. Firms located outside the capital city region are less likely to accept online orders. This is true for domestic firms and for foreign owned firms located in the west of Ireland. These differentials in the ICT diffusion across regions may reflect supply effects related to the uneven provision of ICT infrastructure such as ISDN lines and broadband.

The probability of using both a web site and accepting online orders is positively associated with the share of clerical workers, export intensity, location in the capital city region, the share of firms in the same industry and in the same region that have a website as well as the share of firms in the same industry and in the same region that accept online orders. In contrast, firms with less than 20 employees, older firms, less skill intensive and less export intensive firms are more likely not to have website and not to accept online orders.

With respect to the intensity of using ICT, we find that the share of employees using computers is higher the younger the firm is, for skill-intensive firms, and for firms located in the capital city region. Domestic firms with a high export intensity have a higher share of employees using computers. Being located in the same industry and in the same region with a high share of firms that have a website is positively associated with the share of employees using computers. The share of online transactions is positively associated with firm size and export intensity and there are positive epidemic effects from the share of firms located in the same industry and region that accept online orders.

Whether and to what extent a wider and faster ICT diffusion is desirable is beyond the scope of this paper. The literature on public policy related to technology diffusion (Stoneman and Diederen, 1994) points to three sources of market failure which might justify policy intervention to speed up the diffusion of ICT: imperfect information, market structure and externalities to adoption. Furthermore, policy intervention can be justified on the ground that the market may not provide a satisfactory distribution of the benefits of ICT across firms, industries, space, and time.

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Appendix: Description of Variables and Summary Statistics

Variable	Description	Source	Mean	Std.Dev
web	1 if firm has a website; 0 otherwise	ECS	0.494	0.500
ns	1 if firm accepts online orders; 0 otherwise[a]	ECS	0.129	0.335
empucomp	share of employees using a computer	ECS	0.337	0.294
esale	share of turnover due to transactions over the internet including website, email and electronic data interchange (EDI)	ECS	0.016	0.081
d*ln*to	turnover growth rate[b]	ECS+CIP	0.016	0.301
*ln*wpe	wages per employee[b]	CIP	3.045	0.394
mantech	share of managerial and technical employees	CIP	0.145	0.127
clerical	share of clerical employees	CIP	0.131	0.138
age	firm age (earliest year recorded is 1900)	CIP	17.510	17.653
exint	share of turnover exported	CIP	0.245	0.362
conc	Herfindahl-Hirschman index computed at 3-digit NACE level	CIP	0.072	0.121
multi	1 if enterprise has more than one plant; 0 otherwise	CIP	0.033	0.178
epid_indreg_web	share of firms with a website in all firms in the same 2-digit NACE sector and NUTS3-region	CIP	0.485	0.242
epid_ind_web	share of firms with a website in all firms in the same 2-digit NACE sector but not in the same NUTS3-region	CIP	0.472	0.178
epid_indreg_ns	share of firms accepting online orders in the same 2-digit NACE sector and NUTS3-region	EPS+CIP	0.118	0.171
epid_ind_ns	share of firms accepting online orders in the same 2-digit NACE sector but not in the same NUTS3-region	EPS+CIP	0.113	0.095

[a] replaced to 1 if equal to zero and esale had positive value.

[b] monetary values expressed in thousand euros in 2000 prices. Turnover data were deflated using the sector level producer price index reported by the CSO; wage data were deflated using the consumer price index.

CIP: Census of Industrial Production; ECS: Survey of E-Commerce and ICT