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

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Abstract: We analyse factors driving ICT adoption at firm level using data from Irish manufacturing firms over the period 2001-2004. Our results indicate that the adoption of ICT has been uneven across firms, industries and space. On average, other things equal, firms with more skilled workers, firms operating in ICT-producing and ICT-using industries, 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 region and industry. To a certain extent, patterns of ICT adoption are different for domestic and foreign-owned firms, in particular with respect to the effects of international competitive pressure and firm size.

Key words: ICT adoption, 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. Specifically, the question we are investigating 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 relate a number of ICT adoption indicators to characteristics of firms and features of the environment in which firms operate as suggested by the existing theoretical and empirical literature on new technology adoption.

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 very limited. Second, from the policy

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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.

The novelty of our contribution is threefold. First, we control for firm heterogeneity and distinguish between foreign-owned and domestic firms. Second, we account for industry, region and time specific effects which reduces the omitted variables bias. Third, we estimate technology spillover effects from interactions between firms. In particular, we estimate the effects on ICT adoption at firm level from proximity to firms that have adopted ICT located in the same region and industry.

Our research results indicate that the adoption of ICT in Irish manufacturing has been uneven across firms, industries and space. On average, other things equal, firms with more skilled workers, firms operating in ICT-producing and ICT-using industries, and firms located in the capital city region have been relatively more successful in adopting and using ICT. To a certain extent, patterns of ICT adoption have been different for domestic and foreign-owned firms in particular with respect to the effects of international competitive pressure and firm size. Proximity to firms that have adopted ICT is positively associated with the share of employees using computers at firm level and the share of turnover due to online transactions.

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 adoption. This literature points to delays in the adoption of new technologies and differences in adoption rates across firms, industries and countries[1]. To understand the adoption and diffusion of ICT as a new technology it is therefore essential to uncover the factors that explain this delay and the variation in the rates of its adoption.

The existing theoretical models focus on a number of factors explaining this delay and the variation in the adoption rates including: uncertainty about the characteristics of the new technology (Jensen, 1982), strategic considerations, such as differences in profit rates before and following the technology adoption depending on market structure (Reinganum, 1981), learning by doing processes (Jovanovic and Lach, 1989; Jovanovic and MacDonald, 1994), and differences in human capital (Nelson and Phelps, 1966; Rosenberg, 1972; Chari and Hopenhayn, 1991).

The related empirical studies have looked at two groups of factors affecting new technology adoption: 1) firm characteristics such as sectoral specialisation, firm size, skill composition of the work force, and organisational structure; and 2) characteristics of the local industrial structure such as network externalities, information and knowledge spillovers, and competitive pressure.

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 the adoption of new technologies is more likely when the size of firms is larger. 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 with small firms. Given the high risks and costs of early adoption they are in a better position to adopt

[1] For a recent survey of new technology diffusion models see Geroski (2000).

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; 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 correlated with 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 the 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; Bresnahan et al., 2002, Fabiani et al., 2005; Falk, 2005; Bayo-Moriones and Lera-López).

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

[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.

complementary to worker skills. Black and Lynch (2001, 2004) find that firms in the US that improved their internal organisation to incorporate more high performance practices in conjunction with ICT experienced high productivity growth.

The second group of factors affecting the adoption of new technologies includes characteristics of the environment in which firms operate such as firm density, information and knowledge spillovers, network externalities, and competitive pressure. 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 might 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.

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 are more inclined to innovate and adopt new technologies. Hollenstein (2004) and Bayo-Moriones and Lera-López (2007) find evidence showing that firms that export are more likely to use the Internet.

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, 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 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. The most recent information available from the Census of Industrial Production is for 2004, hence the merged dataset covers the period 2002-2004 for most variables. All information related to transaction volumes 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 50 percent of the enterprises in each year and is representative of the population with respect to the size distribution, the industry classification and the regional distribution of manufacturing activity. 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.

The final working sample includes the core manufacturing industries.[4] Furthermore, 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, 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

[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] 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 estimations.

percentiles of the distribution. We accumulate outliers and delete all firms that have one or more outliers according to this definition.

We construct five measures for ICT adoption at firm level including three discrete variables and two continuous variables:

- *ucomp*: 1 if the firm uses computers, 0 otherwise;
- *netord*: 1 if the firm accepts or has received orders via the Internet, 0 otherwise;
- *servind*: an index of services offered online (marketing of the enterprise's products; facilitating access to product catalogues and price lists; customised page for repeat clients; delivering digital products; providing after sales support); the index takes values ranging from 0 to 5; the index is equal to 1 if only one of these services is offered; 2 if two services are offered; 3, if three services are offered; 4, if four services are offered; 5, if all of these services are offered; the index is equal to 0 if none of these services are offered online.
- *empucomp*: the share of employees using a computer in the total number of employees;
- *esal*: the share of sales (turnover) due to transactions over the Internet including a website, email, and electronic data interchange (EDI).

We employ a taxonomy of ICT industries developed first by Stiroh (2002) for the US and validated in the case of European countries by O'Mahony and van Ark (2003). We distinguish three groups of industries depending on whether they produce or use ICT: ICT-producing manufacturing, ICT-using manufacturing, and non-ICT manufacturing. Details on industry classification and the ICT taxonomy are given in Appendix 1.

Table 1 provides summary statistics related to our discrete variables, namely the use of computers (*ucomp),* whether the company accepts/has received online orders (*netord)* and the composite index of the number of services offered online (*servind)*. Table 1 shows that by 2004 nearly all firms in the sample are using computers and over 50 percent of the firms in the sample offer at least one service online. The share of firms accepting orders online has also increased over the analysed period to just over 16 percent in the sample. Nearly all of the foreign-owned firms use computers; and on average they offer more services online. The shares of firms accepting/having received online orders do not differ much between domestic and foreign-owned firms.

Table 1 Indicators of ICT Adoption: Summary Statistics of Discrete Variables

	Firms	% of firms using computers	% of firms offering x services online						Firms	% firms accepting/ having received orders online
			0	1	2	3	4	5		
Year										
2001									1,852	10.6
2002	1,748	88.0	62.0	18.0	12.8	4.9	1.8	0.6	2,216	10.9
2003	2,121	91.3	59.7	18.9	14.1	5.3	1.4	0.7	1,694	14.5
2004	1,459	96.2	47.8	25.6	17.3	6.4	2.0	0.8	1,267	16.1
Ownership										
domestic	4,475	90.1	60.7	19.3	13.5	4.5	1.5	0.5	5,840	12.5
foreign	853	99.4	38.4	26.4	20.4	10.5	2.6	1.8	1,189	13.3
Total	**5,328**	**91.6**	**57.2**	**20.4**	**14.6**	**5.5**	**1.7**	**0.7**	**7,029**	**12.6**

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

Table 2 provides summary statistics on turnover (*to*), the average wage per employee (*wpe*), the share of employees using a computer (*empucomp*), the share of sales transacted electronically (*esal*) including both transactions over the Internet as well as transactions via electronic data interchange[5], by firm size class, region, ICT industry group, year and ownership. ICT use is higher in the 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 sales due to Internet transactions are the largest in the capital city region. The industries classified as ICT-producing are also ahead of the ICT-using and the non-ICT sectors in terms of ICT adoption and use. In addition to having higher turnover and paying higher wages, nearly 50% of the employees in foreign-owned firms use a computer. The foreign-owned firms earn on average 3% of their turnover with online sales compared to an average of 1.2% among the domestic firms.

[5] 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.

Table 2: Firms Characteristics and ICT Adoption:
Summary Statistics of Continuous Variables

		Turnover in 1,000€		wages per employee in 1,000€		% of employees using computers		% of turnover due to online transactions	
	Firms	Mean	StdDev	Mean	StdDev	Mean	StdDev	Mean	StdDev
Size									
<20	3,577	949	1,605	20.11	0.39	30.3	28.8	1.29	7.10
20-49	1,670	4,723	6,560	24.54	0.34	34.2	28.2	1.08	4.71
50-249	1,260	24,833	68,674	28.15	0.29	37.0	27.3	1.94	9.33
250-499	219	250,473	661,212	32.63	0.29	52.9	28.4	3.37	15.95
>=500	109	1,105,313	2,299,295	35.07	0.25	61.2	27.1	8.11	22.90
NUTS3 region									
border	925	7,873	27,313	19.80	0.37	25.1	23.7	1.90	9.12
midlands	400	7,867	15,902	22.12	0.39	27.4	22.8	0.60	3.93
west	600	12,144	46,108	21.15	0.37	36.4	30.4	1.32	6.01
dublin	1,734	27,705	215,101	26.42	0.37	42.2	31.8	1.92	8.31
mideast	720	28,877	185,638	24.27	0.37	32.8	27.1	1.68	9.15
midwest	601	58,334	700,540	22.91	0.40	34.7	28.6	1.12	5.13
southeast	901	27,402	203,475	22.52	0.36	28.8	25.6	1.02	7.75
southwest	954	75,061	624,007	23.20	0.43	34.7	29.5	1.63	9.72
ICT classification									
ICT-producing	321	250,888	1,099,405	27.10	0.32	57.3	30.4	4.64	17.58
ICT-using	2,505	8,128	65,700	23.15	0.39	39.6	31.1	1.62	8.08
non ICT	4,009	29,186	315,377	23.11	0.40	28.7	25.5	1.23	6.69
Year									
2001	1,801	13,179	106,637	21.00	0.40			1.23	7.50
2002	2,149	22,927	256,551	22.45	0.39	32.5	29.1	1.19	6.84
2003	1,650	41,825	404,599	24.67	0.37	33.6	28.6	1.87	8.87
2004	1,235	61,449	554,370	26.38	0.36	36.7	28.6	2.13	9.55
Ownership									
domestic	5,678	5,851	27,880	21.97	0.39	30.4	27.4	1.24	6.51
foreign	1,157	159,624	824,545	29.88	0.30	49.1	30.1	2.96	13.20
Total	**6,835**	**31,881**	**344,928**	**23.31**	**0.39**	**34.0**	**28.8**	**1.53**	**8.07**

4 Empirical Strategy and Model Specifications

Given the factors that are found relevant for new technology adoption in the literature, we employ measures for firm size, human capital, international competitiveness, firm and industry characteristics as explanatory variables in our regressions. We measure firm size with turnover (*to*). To proxy for human capital we use the average wages per employee (*wpe)*. In addition, we control for the skill composition of employees by including the share of managerial and technical staff in all employees (*mantech)*, and the share of clerical staff including sales representatives in all employees (*clerical)*. Export-intensity (*exint)*, is included as a measure of international competitiveness. We include a dummy variable which indicates whether a firm is a multi-plant firm (*multi).* A further explanatory variable is the age of the firm *(age).* We expect a positive sign on all explanatory variables except *age*.

We also control for unobserved industry-, region- and time-specific effects: λ_j, λ_r, λ_t, respectively are dummy variables for industries grouped according to the ICT taxonomy explained above, regions and years[6]. Definitions and sources of all variables are given in Appendix 2.

The basic model specification estimated for each of the five ICT adoption indicators (Y_{ijrt}) is as follows:

$$Y_{ijrt} = \alpha + \beta_1 \ln to_{ijrt} + \beta_2 mantech_{ijrt} + \beta_3 clerical_{ijrt} + \beta_4 \ln wpe_{ijrt} + \beta_5 ex\,\mathrm{int}_{ijrt} + \beta_6 multi_{ijrt} + \beta_6 age_{ijrt} + \lambda_j + \lambda_r + \lambda_t + \varepsilon_{ijrt} \quad (1)$$

We estimate equation (1) using a probit estimator when our dependent variables are bivariate as is the case with *ucomp* and *netord*. We estimate equation (1) using an ordered probit estimator if our dependent variable is the index of services offered online, *servind*. The estimates related to the discrete dependent variables are shown in Tables 3 and 4. When our dependent variables are continuous taking values between zero and one as is the case for *empucomp* and *esal*, we estimate a fractional logit model. The results related to the continuous dependent variables are shown in Tables 5 and 6. This model was developed by Papke and Wooldridge (1996). It 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 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:

[6] Furthermore we estimate all regressions using industry dummies. While we report relevant differences in the paper, the results of these regressions are available from the authors upon request.

$$E(y_i|x_i) = G(x_i\beta) \tag{2}$$

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

$$E(y_i|x_i) = \frac{\exp(x_i\beta)}{1+\exp(x_i\beta)} \tag{3}$$

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

$$L_i(\beta) = y_i \log[G(x_i\beta)] + (1-y_i)\log[1-G(x_i\beta)] \tag{4}$$

As pointed out above, location and spillover effects from interactions between firms are likely to be two important determinants of ICT adoption at firm level. Firms might benefit from technology spillovers only if they are located near (i.e. within the same region) other firms adopting ICT or if they are part of the same industry. Hence, we calculate horizontal spillover indices considering the ICT adoption activities of the other enterprises located in the same region and industry. Then, for say, industry *j*, region *r* at time *t* the index is:

$$Indreg_{jrt} = \frac{Y^a_{jrt}}{Y_{jrt}}, \tag{5}$$

where *a* indicates the number of enterprises that are using ICT. To capture horizontal spillovers from firms located in different regions (indicated as $\bar{r}$) but in the same industry we also calculate:

$$Ind_{j\bar{r}t} = \frac{Y^a_{jt} - Y^a_{jrt}}{Y_{jt} - Y_{jrt}}. \tag{6}$$

When the share of employees using computers (*empucomp*) is the dependent variable we calculate these spillover terms based on the number of firms using computers; when the share of turnover due to online transactions is the dependent variable they are based on the number of firms accepting electronic orders. The estimated spillover effects are shown in Tables 5 and 6.

In all our regressions the standard errors are adjusted for clustering at the firm level. To fully account for potential endogeneity resulting from unobserved firm characteristics, such as managerial ability, a dynamic panel estimator such as the GMM estimator proposed by Arellano and Bond (1991) would be appropriate. However, our

panel data set is too short. Furthermore, a fixed effects estimator only picks up effects for those firms where there has been a change in status from one period to the next. This is the case for only 12-20 percent of the firms in our sample depending on the chosen discrete dependent variable. This is not satisfactory because it entails throwing away a lot of information. Regarding the continuous dependent variables, the large panel variation in combination with a short time dimension does not make the fixed effects estimator very appealing. Hence, our estimates can be interpreted as upper bound effects.

5 Empirical Results

The estimates obtained in the case of the discrete variables are shown in Table 3. Whether firms use computers is a positive function of their size, the average wage per employee, the share of managerial and technical employees, the share of clerical employees and their export intensity. The older a firm is the less likely it is to use computers. The average wage per employee and the share of managerial and technical employees do not have a significant impact on computer use when 2-digit industry dummies are included instead of the ICT groups.[7] The number of services offered online is positively associated with firm size, the share of highly skilled employees (managerial and technical staff as well as clerical employees) and the export intensity of a firm. Firm age has a negative impact here as well.

Whether firms received/accepted online orders is a positive function of the share of clerical employees and the export intensity. Here the geographical location also plays a substantial role. Firms in all regions except in the West and Mideast have a significantly lower probability of receiving/accepting online orders than firms located in the capital city region. In all three models the time dummies indicate a positive time trend in the adoption of ICT even over the short period.

In all models the probability of adopting the ICT strategy under consideration is higher in ICT-using industries than in the non-ICT sector. For the number of services offered online this is also true for ICT-producing industries. The effect is larger in the ICT-producing than in the ICT-using sectors although the difference between the two coefficients is not statistically significant[8].

When the probability of a company accepting/receiving online orders is the dependent variable, the significance levels of the right-hand side variables do not change substantially. Surprisingly, in this specification also the coefficient on age is positive, which may be plausible if firm age is associated with reputation building. Here, only being in an ICT-using sector increases significantly the probability of a firm accepting/having received orders online relative to being in a non-ICT sector.

There has been a lot of discussion about the 'duality' of the Irish economy in the sense that the foreign firms have very different business motivations and characteristics in comparison to the population of domestic firms (Barry and Bradley, 1997). To account for these differences, we distinguish between domestic and foreign firms and

[7] The results of the regression with industry dummies are available from the authors upon request.
[8] The test statistics for the null hypothesis of equality of coefficients for ICT-producing and ICT-using industries are as follows: *ucomp:* χ^2= 0.90 [p=0.34]; *servind*: χ^2= 0.34 [p=0.56]; *netord*: χ^2= 0.10 [p=0.75]

estimate the models explaining the number of services offered online and whether a firm accepts/has received online.[9] The results are shown in Table 4.

In the case of the number of services offered online, the results for the domestic and the foreign firms do not differ very much, both with respect to size and sign of the coefficients. The only notable difference is the coefficient on export intensity which is only significant for the domestic firms. This result reflects the fact that virtually all foreign-owned firms are exporters, while the domestic firms have on average much smaller export intensities and the share of non-exporters among them is much larger.

[9] The regression for whether firms use computers are not replicated as the number of foreign-owned firms that do not use computers is too small to warrant reliable estimation results.

Table 3 Determinants of ICT Adoption: Estimates of Probit Regressions

Dependent Variable	does firm use computers			no of services offered online			firm accepts/ has received orders online		
lnto	1.537	(0.000)	***	1.132	(0.000)	***	0.989	(0.642)	
lnwpe	1.286	(0.023)	**	1.110	(0.191)		1.022	(0.802)	
mantech	2.388	(0.005)	***	2.659	(0.000)	***	1.338	(0.129)	
clerical	6.440	(0.000)	***	3.599	(0.000)	***	2.327	(0.000)	***
age	0.995	(0.014)	**	0.997	(0.007)	***	1.003	(0.042)	**
exint	1.417	(0.040)	**	1.531	(0.000)	***	1.238	(0.013)	**
multi	1.374	(0.592)		1.117	(0.308)		0.911	(0.516)	
border	0.810	(0.096)	*	0.913	(0.243)		0.819	(0.037)	**
midlands	0.791	(0.138)		0.875	(0.184)		0.637	(0.000)	***
west	1.107	(0.519)		1.046	(0.599)		0.941	(0.556)	
mideast	1.035	(0.819)		0.925	(0.347)		0.823	(0.056)	*
midwest	0.821	(0.166)		0.923	(0.397)		0.757	(0.007)	***
southeast	0.967	(0.795)		0.857	(0.039)	**	0.670	(0.000)	***
southwest	0.902	(0.439)		0.872	(0.059)	*	0.727	(0.001)	***
2002							1.041	(0.367)	
2003	1.251	(0.000)	***	1.011	(0.701)		1.200	(0.000)	***
2004	1.648	(0.000)	***	1.200	(0.000)	***	1.248	(0.000)	***
constant	0.062	(0.000)	***	6.947	(0.000)	***	0.251	(0.000)	***
ICT producing	1.817	(0.091)	*	1.434	(0.000)	***	1.082	(0.525)	
ICT using	1.295	(0.001)	***	1.349	(0.000)	***	1.126	(0.041)	**
Obs	5181			5217			6835		
Firms	2894			2893			3236		
LogL	-1108.6			-5733.0			-2446.7		
R^2 pseudo	0.25			0.07			0.03		

Odds ratios and p-values reported. ***, **, * indicate significance at 1%, 5%, 10%, respectively. Omitted categories: region: Dublin, year: 2001 in the last column, 2002 otherwise, ICT category: non-ICT manufacturing.

When the dependent variable is whether a firm accepts/has received orders online, the differences between the domestic and the foreign-owned firms are more substantial. The share of clerical employees and the export intensity are important determinants of ICT adoption only in the case of the domestic firms. In the case of the foreign-owned firms, the probability of accepting/receiving orders online is negatively associated with the average wage and positively associated with the share of managerial and technical employees. This might suggest that only those foreign-owned firms that are managed from within Ireland operate their online sales from Ireland, while for the bulk of online sales in foreign-owned firms this is probably done from their headquarters. Both

domestic and foreign firms located outside the capital city region are less likely to accept/receive orders online.

Table 4: Determinants of ICT Adoption: Estimates of Probit Regressions distinguishing between domestic and foreign-owned Firms

Dependent Variable	does firm use computers	no of services offered online		firm accepts/has received orders online	
	domestic firms	domestic firms	foreign firms	domestic firms	foreign firms
lnto	1.561 (0.000) ***	1.156 (0.000) ***	1.130 (0.000) ***	0.990 (0.696)	1.039 (0.428)
lnwpe	1.263 (0.037) **	1.089 (0.332)	1.178 (0.424)	1.113 (0.251)	0.559 (0.015) **
mantech	2.372 (0.005) ***	2.900 (0.000) ***	2.333 (0.021) **	1.133 (0.580)	2.125 (0.056) *
clerical	7.013 (0.000) ***	3.470 (0.000) ***	3.288 (0.010) ***	2.484 (0.000) ***	1.356 (0.588)
age	0.994 (0.007) ***	0.996 (0.007) ***	0.995 (0.068) *	1.003 (0.046) **	1.001 (0.799)
exint	1.238 (0.280)	1.990 (0.000) ***	0.912 (0.530)	1.488 (0.000) ***	0.881 (0.499)
multi	1.377 (0.601)	1.254 (0.077) *	0.865 (0.415)	0.861 (0.358)	0.971 (0.913)
border	0.817 (0.121)	0.824 (0.025) **	1.383 (0.076) *	0.756 (0.008) ***	1.027 (0.913)
midlands	0.783 (0.130)	0.785 (0.035) **	1.233 (0.393)	0.660 (0.001) ***	0.513 (0.028) **
west	1.103 (0.541)	1.043 (0.648)	0.977 (0.904)	1.021 (0.851)	0.524 (0.018) **
mideast	1.013 (0.931)	0.923 (0.379)	0.881 (0.535)	0.832 (0.095) *	0.764 (0.296)
midwest	0.807 (0.139)	0.945 (0.583)	1.015 (0.944)	0.773 (0.030) **	0.784 (0.296)
southeast	0.960 (0.758)	0.806 (0.011) **	1.135 (0.441)	0.696 (0.000) ***	0.545 (0.022) **
southwest	0.901 (0.445)	0.888 (0.141)	0.867 (0.361)	0.723 (0.001) ***	0.773 (0.277)
2002				1.069 (0.180)	0.923 (0.444)
2003	1.224 (0.000) ***	1.012 (0.699)	1.043 (0.557)	1.247 (0.000) ***	1.039 (0.731)
2004	1.618 (0.000) ***	1.205 (0.000) ***	1.210 (0.018) **	1.280 (0.000) ***	1.143 (0.267)
constant	0.060 (0.000) ***	7.689 (0.000) ***	6.531 (0.003) ***	0.184 (0.000) ***	1.586 (0.553)
ICT producing	1.763 (0.128)	1.407 (0.026) **	1.685 (0.000) ***	0.997 (0.988)	1.171 (0.318)
ICT using	1.320 (0.001) ***	1.343 (0.000) ***	1.521 (0.000) ***	1.156 (0.020) **	1.085 (0.625)
Obs	4349	4385	832	5678	1157
Firms	2460	2460	446	2757	494
LogL	-1076.0	-4554.8	-1132.0	-2001.8	-418.965
R^2 pseudo	0.23	0.07	0.05	0.04	0.045

Odds ratios and p-values reported. ***, **, * indicate significance at 1%, 5%, 10%, respectively.

Omitted categories: region: Dublin, year: 2001 in the last two columns, 2002 otherwise, ICT category: non-ICT manufacturing.

The number of foreign-owned firms that start using computers is too small to obtain reliable estimates.

We now turn to ICT adoption measured by continuous variables as shown in Table 5.

Table 5: Determinants of ICT Adoption: Estimates of Fractional Logit Regressions

	share of employees using computers				share of turnover due to online transactions			
	(1)		(2)		(3)		(4)	
lnto	0.027	(0.020)	0.017	(0.020)	0.203	(0.101) **	0.227	(0.084) ***
lnwpe	0.683	(0.087) ***	0.607	(0.086) ***	-0.488	(0.308)	-0.391	(0.300)
mantech	2.386	(0.220) ***	2.200	(0.221) ***	0.799	(0.594)	0.375	(0.578)
clerical	2.856	(0.180) ***	2.591	(0.175) ***	0.104	(0.581)	-0.622	(0.539)
age	-0.003	(0.001) *	-0.003	(0.001) *	-0.003	(0.005)	-0.005	(0.005)
exint	0.416	(0.076) ***	0.324	(0.076) ***	0.928	(0.276) ***	0.722	(0.250) ***
multi	0.026	(0.114)	0.042	(0.112)	-0.921	(0.462) **	-1.390	(0.468) ***
ind-reg sp			2.319	(0.225) ***			5.458	(0.365) ***
ind sp			0.895	(0.238) ***			0.323	(0.745)
border	-0.423	(0.081) ***	-0.347	(0.080) ***	-0.209	(0.312)	-0.073	(0.304)
midlands	-0.398	(0.099) ***	-0.306	(0.102) ***	-0.934	(0.416) **	-0.686	(0.383) *
west	-0.036	(0.098)	0.007	(0.096)	-0.403	(0.293)	-0.785	(0.329) **
mideast	-0.213	(0.089) **	-0.225	(0.088) **	-0.277	(0.405)	-0.295	(0.320)
midwest	-0.197	(0.098) **	-0.151	(0.096)	-0.759	(0.310) **	-0.738	(0.302) **
southeast	-0.274	(0.081) ***	-0.256	(0.081) ***	-0.608	(0.443)	-0.495	(0.381)
southwest	-0.108	(0.079)	-0.081	(0.078)	-0.213	(0.422)	0.031	(0.409)
2002					0.001	(0.131)	-0.042	(0.142)
2003	0.022	(0.034)	-0.075	(0.035) **	0.331	(0.149) **	0.045	(0.159)
2004	0.025	(0.040)	-0.189	(0.044) ***	0.376	(0.146) ***	0.052	(0.163)
constant	-3.884	(0.248) ***	-6.350	(0.330) ***	-4.721	(0.657) ***	-5.960	(0.664) ***
ICT producing	0.754	(0.120) ***	0.614	(0.122) ***	0.406	(0.334)	0.175	(0.310)
ICT using	0.448	(0.051) ***	0.387	(0.051) ***	0.330	(0.252)	0.169	(0.241)
Obs	4,689		4,689		6,188		6,188	
Firms	2,707		2,707		3,041		3,041	
LogL	-2096.6		-2060.6		-402.1		-346.2	
χ^2	903.7		1072.1		110.7		395.8	

Standard errors in parenthesis. ***, **, * indicate significance at 1%, 5%, 10%, respectively. Omitted categories are: region: Dublin, year: 2002 in columns 1-2, 2001 in columns 3-4, ICT category: non-ICT manufacturing. ind-reg sp: share of firms in the same industry and region that use computers in column 2 , share of firms in the same industry and region that accept/have received orders online in column 4; ind sp: share of firms in the same industry but not in the same region that use computers in columns 2, share of firms in the same industry but not in the same region that accept/have received orders online in column 4. Industry-year cells with only one firm are not included.

The results from the fractional logit model for the share of employees using computers – shown in columns 1 and 2 of Table 5 – indicate again a high importance of human capital for ICT adoption. In particular, the share of managerial and technical employees and the share of clerical employees have large positive and significant coefficients. A high export intensity is also associated with a larger share of employees using computers. Firm age has a small negative effect here. A location outside the capital city

region is associated with a negative impact on the share of employees using computers. The share of employees using computers is significantly higher in ICT-producing and ICT-using industries relative to non-ICT industries. The difference between the ICT-producing and the ICT-using sectors is significant at the 5 percent level.[10] When we include industry dummies instead of the ICT groups, not all of the region effects retain their significance[11].

The second column of Table 5 shows the results obtained from the augmented model to include spillover effects. Both spillover terms are positive and significant. This suggests that there are agglomeration effects, i.e. being located in an industry and region where a large share of firms using computers has a positive effect on the share of employees using computers in a firm[12]. The difference between ICT-producing and ICT-using industries is only marginally significant[13].

Columns 3 and 4 of Table 5 show the estimates for the share of turnover due to online transactions. The results indicate that firm size and export intensity are positively associated with this measure of ICT adoption. Multi-plant firms are associated with lower shares of turnover transacted online. 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 of all sectors.[14] The coefficients on the regions have a negative sign, but only a few of them are significant. The ICT category dummies do not suggest that there are differential effects from being in one ICT grouping rather than another. When the industry dummies are included instead, their joint significance indicates that there are industry-specific effects to online sales. When the variables controlling for spillover effects are included, those determinants that were significant before retain their significance. In addition, there is a strong positive effect from being located in an industry and region with a large share of firms accepting/having received orders online.

[10] The test statistics for the null hypothesis of equality of coefficients for ICT-producing and ICT-using industries is χ^2= 5.89 [p=0.02].
[11] The results of the regressions with industry dummies are available from the authors upon request.
[12] The positive effect from being in the same industry, but not in the same region where a large share of firms are using computers does not retain its significance when the ICT dummies are replaced by industry dummies. This suggests that industry-specific spillover effects pick up non-observed industry characteristics not controlled for when using the ICT taxonomy. These results not reported here are available from the authors upon request.
[13] The test statistics for the null hypothesis of equality of coefficients for ICT-producing and ICT-using industries is χ^2= 3.16 [p=0.08].
[14] However the share of multi-unit enterprises in the NACE sector 15 (Food and Beverages) is also substantial and the average share of turnover due to online transactions is close to the average of the manufacturing sector as a whole.

In Table 6 we present the estimates of the share of employees using computers where we allow the relationships to differ for domestic and foreign-owned firms. We augment the model by including interacted variables with a dummy which takes the value 1 for foreign-owned firms and 0 otherwise. The coefficients for the domestic firms are largely similar to those in the regression when all firms are included. For the foreign firms the effects of firm size and human capital differ in comparison to domestic firms. Large foreign firms have a higher share of employees using computers. The effect of the share of managerial and technical employees is even stronger for the foreign-owned firms with respect to the number of employees using computers. Finally, age and export intensity are negatively correlated with the share of employees using computers. In both cases, this correlation is weak and only marginally significant.[15] When we control for spillover effects, we find that the size of domestic firms is negatively associated with the share of employees using computers.

We also re-estimate the determinants of the share of turnover due to online transactions allowing for different slopes for domestic and foreign-owned firms. The results are shown in columns 3 and 4 of Table 6. One can see that the large foreign-owned firms drive the positive and significant coefficient on firm size when foreign ownership is not accounted for. Otherwise, there are no noticeable differences between the domestic and the foreign-owned firms in these regressions. A χ^2-test on the joint significance of the interaction terms with the foreign ownership dummies confirms this observation.

[15] This result is in line with the fact that online sales of foreign-owned firms are likely to be managed from the headquarter based in the home country.

Table 6 Determinants of ICT Adoption: Estimates of Fractional Logit Regressions with Different Effects for Domestic and Foreign-owned Firms

Dep. Variable	share of employees using computers		share of turnover due to online transactions	
	(1)	(2)	(3)	(4)
lnto	-0.035 (0.024)	-0.051 (0.023) **	0.043 (0.103)	0.105 (0.103)
lnwpe	0.701 (0.092) ***	0.621 (0.089) ***	-0.058 (0.312)	-0.064 (0.333)
mantech	2.083 (0.255) ***	1.869 (0.257) ***	-0.229 (0.828)	-0.254 (0.760)
clerical	2.858 (0.192) ***	2.556 (0.187) ***	0.505 (0.367)	-0.345 (0.425)
age	-0.001 (0.001)	-0.001 (0.001)	0.000 (0.005)	-0.003 (0.005)
exint	0.355 (0.098) ***	0.279 (0.097) ***	1.215 (0.309) ***	0.693 (0.282) **
multi	0.005 (0.121)	0.020 (0.122)	-0.984 (0.484) **	-1.387 (0.479) ***
fo	-0.843 (0.854)	-1.604 (0.848) *	1.313 (2.771)	1.176 (2.908)
fo_lnto	0.153 (0.044) ***	0.170 (0.044) ***	0.313 (0.156) **	0.234 (0.151)
fo_lnwpe	-0.002 (0.298)	0.129 (0.295)	-1.302 (0.982)	-1.182 (1.053)
fo_mantech	1.238 (0.460) ***	1.303 (0.463) ***	2.030 (1.447)	1.405 (1.425)
fo_clearical	-0.132 (0.512)	0.170 (0.514)	-1.448 (2.103)	-0.772 (1.897)
fo_age	-0.007 (0.004) *	-0.006 (0.004) *	0.000 (0.013)	0.004 (0.011)
fo_exint	-0.377 (0.194) *	-0.296 (0.195)	-0.355 (0.589)	0.497 (0.610)
ind-reg sp		2.376 (0.226) ***		5.464 (0.377) ***
ind sp		0.856 (0.234) ***		0.242 (0.757)
border	-0.419 (0.082) ***	-0.336 (0.080) ***	-0.202 (0.314)	-0.063 (0.308)
midlands	-0.388 (0.100) ***	-0.290 (0.101) ***	-0.892 (0.412) **	-0.658 (0.378) *
west	-0.031 (0.096)	0.018 (0.095)	-0.344 (0.280)	-0.755 (0.333) **
mideast	-0.200 (0.089) **	-0.210 (0.087) **	-0.276 (0.378)	-0.326 (0.306)
midwest	-0.210 (0.098) **	-0.156 (0.096)	-0.751 (0.307) **	-0.777 (0.322) **
southeast	-0.270 (0.081) ***	-0.246 (0.080) ***	-0.595 (0.456)	-0.490 (0.388)
southwest	-0.122 (0.078)	-0.090 (0.078)	-0.217 (0.424)	0.028 (0.412)
2002			-0.016 (0.134)	-0.056 (0.147)
2003	0.020 (0.034)	-0.079 (0.035) **	0.324 (0.150) **	0.045 (0.163)
2004	0.025 (0.040)	-0.192 (0.044) ***	0.367 (0.147) **	0.071 (0.167)
constant	-3.481 (0.262) ***	-5.903 (0.336) ***	-4.812 (0.680) ***	-5.968 (0.704) ***
ICT producing	0.667 (0.127) ***	0.540 (0.129) ***	0.292 (0.330)	0.007 (0.336)
ICT using	0.437 (0.051) ***	0.375 (0.050) ***	0.294 (0.251)	0.107 (0.248)
Obs	4,689	4,689	6,188	6,188
Firms	2,707	2,707	3,041	3,041
LogL	-2085.4	-2048.8	-398.5	-343.9
χ^2	1065.2	1213.8	131.9	408.1

Standard errors in parenthesis. ***, **, * indicate significance at 1%, 5%, 10%, respectively. Omitted categories are: region: Dublin, year: 2002 in columns 1-2, 2001 in columns 3-4, ICT category: non-ICT manufacturing.
ind-reg sp: share of firms in the same industry and region that use computers in column 2 , share of firms in the same industry and region that accept/have received orders online in column 4; ind sp: share of firms in the same industry but not in the same region that use computers in columns 2, share of firms in the same industry but not in the same region that accept/have received orders online in column 4. Industry-year cells with only one firm are not included.

6 Concluding Remarks

In this paper we examine factors driving the adoption of ICT at firm level using data from a sample of 3,400 firms in Irish manufacturing industries between 2001 and 2004. We use an analytical framework suggested by the theory of new technology adoption and relate indicators of ICT adoption such as the usage of computers, services offered online, online transactions to two sets of factors. These latter factors are characteristics of firms (size, age, industry specialisation, human capital) and characteristics of the environment in which firms operate (geographical location, technology spillovers).

Our main findings can be summarised as follows. The likelihood of computer usage is positively associated with firm size, the share of clerical employees and export intensity. The share of employees using computers is positively associated with human capital (proxied with the share of highly skilled employees and the average wage per employee) as well as export intensity. The share of employees using computers is relatively smaller in firms located outside the capital city region and in non-ICT industries. Further, we find that in industries and regions with a high share of firms using computers the share of employees using computers is higher. Moreover, the share of turnover due to online transactions is higher in industries and regions with a large share of firms that carry out their transactions online. This points to the importance of technology spillovers from interactions between firms in the adoption of ICT. Older firms are less likely to use computers. The larger a firm, the more services it is likely to offer online. Firms located in the capital city region are more likely to accept orders online. We find evidence showing that ICT adoption has increased over time. Firms in ICT-producing and ICT-using industries are more likely to use computers and offer a larger number of services online. Firms in ICT-using industries are more likely to accept orders online.

To a certain extent, patterns of ICT adoption have been different for domestic and foreign-owned firms. First, while international competitive pressure proxied by export intensity is positively associated with ICT adoption in the case of domestic firms, it does not have a significant effect in the case of foreign-owned firms. Second, while firm size is positively associated with the share of employees using computers in the case of foreign-owned firms, it is negatively associated with firm size in the case of domestic firms. The effect of firm size on the share of online transactions is also different for domestic and foreign-owned firms. However, firm size has a positive effect on the number of services offered online in domestic firms and no significant effect in the case of foreign-owned firms.

These findings suggest that the adoption of ICT in Irish manufacturing has been uneven across firms, industries and space. On average, other things equal, firms with more skilled workers, operating in ICT-producing and ICT-using manufacturing, and firms located in the capital city region have been relatively more successful in adopting and using ICT. Proximity to firms that have adopted ICT is positively associated with the share of employees using computers at firm level and the share of turnover due to online transactions. These results are in line with the theoretical and empirical literature on new technology adoption which points to delays in the adoption of the new technology and differences in adoption rates.

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.

References

Arellano, M. and S. Bond (1991), "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations", *Review of Economic Studies*, 58(2): 277–297.

Arvanitis, S. (2005) "Computerization, Workplace Organization, Skilled Labour and Firm Productivity: Evidence for the Swiss Business Sector", *Economics of Innovation and New Technology* 14(4), 225-249.

Barry, F. and J. Bradley (1997) "FDI and Trade: The Irish Host-Country Experience", *Economic Journal*, vol. 107, no. 445, 1798-1811.

Bartel, A. and N. Sicherman (1999) "Technological Change and Wages: An Interindustry Analysis", *Journal of Political Economy*, 107, 285-325.

Baptista, R. (2000) "Do Innovations Diffuse Faster Within Geographical Clusters?", *International Journal of Industrial Organization*, 18(3), 515-535.

Bassanini, A. and S. Scarpetta (2002) "Growth, Technological Change, and ICT Diffusion: Recent Evidence from OECD Countries", *Oxford Review of Economic Policy*, 18 (3), 324-344.

Bayo-Moriones, A. and F. Lera-López (2007) "A Firm Level Analysis of Determinants of ICT Adoption in Spain", *Technovation*, 27(6-7), 352-366.

Beccheti, L., D.A. Londono Bedoya, L. Paganetto, L. (2003) "ICT Investment, Productivity and Efficiency: Evidence at Firm Level using a Stochastic Frontier Approach", *Journal of Productivity Analysis*, 20(2), 143-167.

Black, S. and L. Lynch (2001) "How to Compete: The Impact of Workplace Practices and Information Technology on Productivity", *Review of Economics and Statistics*, vol. 83(3), 434-45.

Black, S. and L. Lynch (2004), "What's Driving the New Economy?: The Benefits of Workplace Innovation", *The Economic Journal*, 114, 97-116.

Bresnahan, T.F. and M. Trajtenberg (1995) "General Purpose Technologies: 'Engines of Growth?", *Journal of Econometrics*, 65, 83-108.

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

Brynjolfsson, E. and L. Hitt (2000) "Beyond Computation: Information technology, Organizational Transformation and Business Performance", *Journal of Economic Perspectives*, 14, 23-48.

Brynjolfsson, E. and L. Hitt (2003) "Computing Productivity: Firm Level Evidence", *The Review of Economics and Statistics*, 85(4), 793-808.

Carlsson, B. (2004) "The Digital Economy: What is New and What is Not?", *Structural Change and Economic Dynamics*, 15(3), 245-264.

Caroli, E. and J. van Reenen (2001) "Skill-biased organisational change? Evidence from a panel of British and French establishments", *Quarterly Journal of Economics*, 116, 1449-1492.

Caselli, F. and W. Coleman (2001) "Cross-country Technology Diffusion: The Case of Computers", *American Economic Review*, 91(2), 328-335.

Chari, V.V. and H. Hopenhayn (1991) "Vintage Human capital, Growth and the Diffusion of New Technology", *Journal of Political Economy*, 99, 1142-1165

Cheung, W. M. and W. Huang (2002) "An Investigation of Commercial Usage of the World Wide Web: A Picture from Singapore", International Journal of Information Management, 22 (5), 377-388.

Chun, H. (2003) "Information Technology and the Demand for Educated Workers: Disentangling the Impacts of Adoption versus Use", *The Review of Economics and Statistics*, 85, 1-8.

Cooper, J. and A. John (1998) "Coordinating coordination failures in Keynesian models", *Quarterly Journal of Economics*, 103, 441-464.

Dasgupta, S., D. Agarwal, A. Ioannidis, S. Gopalakrishnan (1999) "Determinants of Information Technology Adoption: An Extension of Existing Models to Firms in

a Developing Country", *Journal of Global Information Management*, 7(3), 30-40.

Doms, M., T. Dunne, K. Troske (1997) "Workers, Wages and Technology", *The Quarterly Journal of Economics*, 112(1), 253-290.

Eaton, J. and S. Kortum (1999) "International Technology Diffusion: Theory and Measurement", *International Economic Review*, 40(3), 537-70.

Fabiani, S., F. Schivardi, S. Trento (2005) "ICT Adoption in Italian Manufacturing: Firm Level Evidence", *Industrial and Corporate Change*, 14(2), 225-249.

Falk, M. (2005) "ICT-linked Firm Reorganisation and Productivity Gains", *Technovation*, 25(11), 1229-1250.

Galliano, D., P. Roux, M. Filippi (2001) "Organisational and Spatial Determinants of ICT Adoption: The Case of French Industrial Firms", *Environment and Planning*, 33(9), 1643-1663 .

Gattignon, H. and T. S. Robertson (1989) "Technology Diffusion: An Empirical Test of Competitive Effects", *Journal of Marketing*, 53(1), 35-49.

Geroski, P.A. (2000) "Models of Technology Diffusion", *Research Policy*, 29, 603-625.

Gourlay, A. and E. Pentecost (2002) "The Determinants of Technology Diffusion: Evidence from the UK Financial Sector", *Manchester School*, 70(2), 185-203.

Helpman, E. and M. Trajtenberg (1998) "Diffusion of General Purpose Technologies", in E. Helpman (ed.), *General Purpose Technologies and Economic Growth*, Cambridge, MA: MIT Press.

Hollenstein, H. (2004) "Determinants of the Adoption of Information and Communication Technologies", *Structural Change and Economic Dynamics*, 15(3), 315-342.

Jaffe, A., M. Trajtenberg, and R. Henderson (1993) "Geographical Localization of Knowledge Spillovers as Evidenced by Patent Citations", *Quarterly Journal of Economics*, 108(3), 577-98.

Jaffe, A. and M. Trajtenberg (1999) "International Knowledge Flows: Evidence from Patent Citations", *Economics of Innovation and New Technology*, 8(1-2), 105-36.

Jensen, R. (1982) "Adoption and Diffusion of an Innovation of Uncertain Profitability", *Journal of Economic Theory*, 27, 182-193.

Jorgenson, D.W. and K. Stiroh (2000) "Raising the Speed Limit: US Economic Growth in the Information Age", *Brookings Papers on Economic Activity*, 1, 125-211.

Jovanovic, B. and S. Lach (1989) "Entry, Exit and Diffusion with Learning by Doing", *American Economic Review*, 79, 690-699.

Jovanovic, B. and G.M. MacDonald (1994) "Competitive Diffusion", *Journal of Political Economy*, 102, 24-52.

Keller, W. (2002) "Geographical Localisation of International Technology Diffusion", *American Economic Review*, 92(1), 120-142.

Kowtha, N.R. and T.W. Choon (2001) "Determinants of Website Development: A Study of Electronic Commerce in Singapore", *Information and Management*, 39(3), 227-242.

Lehr, B. and F. Lichtenberg (1999) "Information Technology and its Impact on Productivity: Firm Level Evidence from Government and Private Data Sources, 1977-1993", *Canadian Journal of Economics*, 32, 335-62.

Lee, J. (2004) "Discriminant Analysis of Technology Adoption Behaviour: A Case of Internet Technologies in Small Business", *Journal of Computer Information Systems* 44(2), 146-157.

Lefebvre L., E. Lefebvre, E. Elia, H. Boek (2005) "Exploring B-to-B E-Commerce Adoption Trajectories in Manufacturing SMEs", *Technovation* 25(12), 1443-1456.

Love, P.E.D., Z. Irani, C. Standing, C. Lin, J.M. Burn (2005) "The Enigma of Evaluation: Benefits, Costs and Risks of IT in Australian Small-Medium-Sized Enterprises", *Information and Management* 42(7), 947-964.

Matteucci, N., M. O'Mahony, C. Robinson, T. Zwick (2005) "Productivity, Workplace Performance and ICT: Industry and Firm-Level Evidence for Europe and the US", *Scottish Journal of Political Economy*, 52(3), 359-386.

Morgan, A., Colebourne, D., B. Thomas (2006) "The Development of ICT Advisors for SME Business: An Innovative Approach", *Technovation* 26(8), 980-987.

Nelson, R.R. and E. S. Phelps (1966) "Investing in Humans, Technological diffusion, and Economic Growth", *American Economic Review*, 56, 69-75.

OECD (2004) *The Economic Impact of ICT, Measurement, Evidence and Implications*, Paris: OECD.

Oliner, S.D. and D.E. Sichel (2000) "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?", *Journal of Economic Perspectives*, 14, 3-12.

O'Mahony, M. and van Ark, B. (eds.) (2003). *EU productivity and competitiveness: An Iindustry Perspective Can Europe resume the catching-up process?*, Luxembourg: European Commission.

Oulton, N. (2002) "ICT and Productivity Growth in the United Kingdom", *Oxford Review of Economic Policy*, 18, 363-79.

Papke, L.E., Wooldridge, J. (1996). "Econometric methods for fractional response variables with an application to 401(k) plan participation rates", *Journal of Applied Econometrics* 11, 619–632.

Porter, M. (2004) *The Competitive Advantage of Nations*, New York: Free Press.

Reinganum, J.F. (1981) "On the Diffusion of new Technology: A Game Theoretic Approach", *Review of Economic Studies*, 48, 395-405.

Rosenberg, N. (1972) "Factors Affecting the Diffusion of Technology", *Explorations in Economic History*, 10(1), 3-33.

Stiroh, K.J., 2002, "Information Technology and the US Productivity Revival: What Do the Industry Data Say?", *American Economic Review*, 92(5), 1559-1576.

Stoneman, P. and P. Diederen (1994) "Technology Diffusion and Public Policy", *The Economic Journal*, 104(425), 918-930

Teo, T.S.H., and C. Ranganathan (2004) "Adopters and non-adopters of buisnss-to-business electronic commerce in Singapore", *Information and Management* 42(1), 89-102.

Teo, T.S.H. and M. Tan (1998) "An Empirical Study of Adopters and Non-Adopters of the Internet in Singapore", *Information and Management* 34(6), 339-345.

Teo, T.S.H., M. Tan, and W.K. Buk (1997) "A Contingency Model of Internet Adoption in Singapore", *International Journal of Electronic Commerce* 2(2), 95-118.

Thong, J.Y.L (1999) "An Integrated Model of Information Systems Adoption in Small Business", *Journal of Management Information Systems* 4(15), 187-214.

Timmer, M. and B. van Ark (2005) "Does Information and Communication Technology Drive EU-US Productivity Growth Differentials?", *Oxford Economic Papers*, 57, 693-716.

Appendix 1: Taxonomy of ICT Industries (NACE Rev. 1.1 codes in brackets)

ICT-producing Manufacturing

Office machinery (30)
Insulated wire (313)
Electronic valves and tubes (321)
Telecommunication equipment (322)
Radio and television receivers (323)
Scientific instruments (331)

ICT-using Manufacturing

Clothing (18)
Printing & publishing (22)
Mechanical engineering (29);
Other electrical machinery & apparatus (31-313)
Other instruments (33-331)
Building and repairing of ships and boats (351)
Aircraft and spacecraft (353)
Railroad equipment and transport equipment nec (352+359)
Furniture, miscellaneous manufacturing (36)

Non-ICT Manufacturing

Food, drink & tobacco (15-16)
Textiles (17)
Leather and footwear (19)
Wood & products of wood and cork (20)
Pulp, paper & paper products (21)
Mineral oil refining, coke & nuclear fuel (23)
Chemicals (24)
Rubber & plastics (25)
Non-metallic mineral products (26)
Basic metals (27)
Fabricated metal products (28)
Motor vehicles (34)

Appendix 2: Description of Variables

Variable	Description	Source
ucomp	1 if enterprise uses computers; 0 otherwise	E-Commerce Survey
servind	index of services offered online: marketing the enterprise's products, facilitating access to product catalogues and price lists, customised page for repeat clients, delivering digital products, providing after sales support	E-Commerce Survey
netord	1 if enterprise accepts/has received orders via the Internet; 0 otherwise	E-Commerce Survey; changed if equal to 0 and esal had a positive value
empucomp	share of employees using a computer in total employees	E-Commerce Survey
esal	share of turnover due to transactions over the Internet including a website, email and electronic data interchange (EDI)	E-Commerce Survey complemented with information from the CIP
age	firm age, current year less start-up year, where the earliest start-up year recorded is 1900	CIP
clerical	share of clerical workers in total employees	CIP
exint	export intensity: share of exports in total sales	CIP
ln to	log of turnover, where turnover is reported in multiples of 1000€ and deflated to constant 2000 values using the producer price index reported by the CSO	CIP
ln wpe	log of earnings and wages per employee, where wages and earnings are reported in multiples of 1000€ and deflated to constant 2000 values using the consumer price index reported by the CSO	CIP
mantech	share or managers and technicians in total employees	CIP
multi	1 if enterprise comprises several plants; 0 otherwise	CIP
NUTS3 regions	border, midlands, west, Dublin, mideast, midwest, southeast, southwest	CIP

CIP: Census of Industrial Production;

E-Commerce Survey: Survey of E-Commerce and ICT

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