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# Determinants of ICT adoption: evidence from firm-level data

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We analyse factors driving inter- and intra-firm diffusion of Information and Communication Technologies (ICT) using data from Irish manufacturing firms over the period 2001 to 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 results suggest that firms that are larger, younger, fast growing, skill-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.

## I. Introduction

There is growing evidence suggesting that Information and Communication Technologies (ICT) are strong determinants of productivity growth differentials as well as the ability of countries to benefit from globalization (Jorgenson and Stiroh, 2000; Oliner and Sichel, 2000; Bassanini and Scarpetta, 2002; Organization for Economic Cooperation and Development (OECD), 2004; Timmer and van Ark, 2005). In addition, existing empirical evidence shows that ICT use contributes to productivity and output growth at the firm level (Lehr and Lichtenberg, 1999; Brynjolfsson and Hitt, 2000, 2003; Matteucci *et al.*, 2005).

In this article, we analyse the patterns and determinants of ICT diffusion at the firm level. We add to the existing empirical literature in two ways. First, in comparison to most of existing empirical studies we estimate theory-based models to test the effects of firm heterogeneity and information spillovers on ICT diffusion. Second, in contrast to

existing cross-section studies, we use a novel panel data set from manufacturing firms in Ireland, which allows us to uncover the ICT diffusion path over time and to alleviate potential endogeneity arising from simultaneity and omitted variable bias.

Uncovering the factors driving ICT diffusion is important and relevant for both research and policy. First, in contrast with a well-established theoretical literature on new technology diffusion, firm-level empirical evidence on ICT 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 diffusion of ICT.

The diffusion of new technology is likely to vary across countries depending on country-specific characteristics such as economic size, distance to the technological frontier, domestic absorptive capacity, economic specialization and openness to trade and investment (Keller, 2004). The case of ICT diffusion in Ireland is interesting given its specialization in ICT industries<sup>1</sup> together with a high degree of openness to

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<sup>1</sup> The share of ICT exports in total exports in Ireland is the highest among the European Union's 27 member states (European Commission, 2009).

trade and investment. In addition, Ireland has both firms that are close to and far from the technological frontier. According to the European Commission (2009), Ireland ranks highly among the EU member states with respect to e-commerce (ranked first on the percentage of enterprises purchasing online, ranked third on the percentage of enterprises selling online and on e-commerce as per cent of total turnover) and e-business (ranked second on the share of enterprises using applications for integrating internal business processes).

Our results suggest that the path of ICT diffusion has been influenced by firm characteristics such as firm size, age, skill intensity, international competition and proximity to early adopters of ICT in the same industry and region.

The remainder of this article is structured as follows. Section II discusses the analytical framework for our empirical analysis and testable hypotheses about the factors driving ICT diffusion across firms, industries and regions. In Section III, we describe our data set and the ICT indicators that we use in our empirical analysis. Section IV outlines our empirical strategy and model specifications. We discuss our main results in Section V. Finally, Section VI summarizes our findings and relates them to the existing theoretical and empirical evidence.

## II. Theoretical and Empirical Background

The theoretical starting point for this analysis is the literature on new technology diffusion.<sup>2</sup> The main prediction of these models is that preferred adoption dates vary across potential adopters of a new technology. To understand the 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 and use across firms, industries, regions and countries.

The early models of new technology diffusion known as *epidemic models* (Mansfield, 1963a, b) assume that the adoption of a new technology depends upon the spread of information about its availability or other 'epidemic-type' learning factors which help to reduce the uncertainty related to new technologies. The learning effects are assumed exogenous and the diffusion path is driven by reductions in cost or quality improvements due to the new technology (Stoneman, 2002). At any point in time, only a fraction 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 associated with adoption decreases due to learning effects across and within firms (Battisti and Stoneman, 2005).

Another group of theoretical models links the variation in the preferred adoption date to differentials in returns (profitability) to potential adopters of new technologies. *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. Consequently, firms with high returns from the adoption of new technology will be early adopters while firms with low returns will be late adopters. *Stock models* assume that the benefit to the marginal adopter from acquiring a new technology decreases with 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* (Fudenberg and Tirole, 1985; Ireland and Stoneman, 1985) assume that the return to a firm from adopting a new technology depends upon its position in the order of adoption: early adopters achieve a greater return than late adopters. Furthermore, the decision of early adopters can affect the adoption date of later 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 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 internalized and appear in the marginal revenue from the adoption of new technology (Stoneman, 2002).

The bulk of existing empirical studies on the determinants of new technology diffusion has focused on inter-firm diffusion or adoption of new technologies by firms, while intra-firm diffusion – the extent of using new technology by firms – has been less investigated (Battisti and Stoneman, 2003, 2005). Empirical evidence suggests that in the earlier stages of adoption inter-firm diffusion prevails, whereas intra-firm diffusion gains importance only later on in

<sup>2</sup> Karshenas and Stoneman (1993), Geroski (2000) and Stoneman (2002) provide excellent surveys of new technology diffusion models.

the diffusion process (Battisti and Stoneman, 2003). While a large number of empirical studies have focused on a single model of new technology diffusion, Karshenas and Stoneman (1993) estimate an empirical model which captures rank, stock, order and epidemic effects simultaneously. Their findings using data on the diffusion of Computer Numerically Controlled (CNC) machine tools in the UK engineering industry from 1968 to 1980 suggest the presence of rank and epidemic effects, but provide little evidence of stock and order effects.

*Rank effects* have been modelled using variables related to firm characteristics, such as firm size, skill composition of the work force and organizational structure.

A stylized fact supported by a large empirical literature is that larger firms are more likely to adopt new technologies early. 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. Large firms might be more motivated and able to innovate in order to pre-empt rivals; also the scope for innovation complementarities is likely to be greater in larger firms. Existing empirical evidence on the relationship between firm size and ICT adoption is mixed. While a number of studies find a positive correlation between firm size and the adoption of ICT (Teo and Tan, 1998; Thong, 1999; Fabiani *et al.*, 2005; Giunta and Trivieri, 2007), other studies find a weak or insignificant relationship (Teo *et al.*, 1997; Lefebvre *et al.*, 2005; Love *et al.*, 2005). Hollenstein (2004) suggests that this relationship might be nonlinear. He finds that in a sample of Swiss firms, firm size is positively related to early and intensive use of ICT<sup>3</sup> 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. Battisti *et al.* (2007) find that while large firms are more likely to adopt ICT in comparison to smaller firms, once they adopted ICT, smaller firms are likely to use ICT more intensively than larger firms.

A large theoretical and empirical literature has focused on the relationship between human capital and new technology adoption. One strand of

literature focuses on the role of education or skills (human capital) in the process of adopting new technologies and shows that a highly educated workforce facilitates an earlier adoption of new technology (Nelson and Phelps, 1966; Bartel and Lichtenberg, 1987; Chun, 2003). A second strand of literature focuses on the new technology-skill complementarity and shows that demand for educated workers rises together with the use of the new technology (Griliches, 1969; Berman *et al.*, 1994; Doms *et al.*, 1997; Haskel and Heden, 1999). Bugamelli and Pagano (2004) report that the lack of investment in human capital and organizational change acted as a barrier to investment in ICT in manufacturing firms in Italy.

Firms facing stronger competition are more inclined to innovate and adopt new technologies, such as ICT, in order to strengthen their performance and chances of survival (Porter, 1990). Several studies show that competitive pressure is positively associated with ICT adoption (Dasgupta *et al.*, 1999; Kowtha and Choon, 2001; Hollenstein, 2004). In contrast, other papers find no significant effect of competitive pressure on ICT adoption (Teo *et al.*, 1997; Thong, 1999; Jeon *et al.*, 2006).

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), Bayo-Moriones and Lera-López (2007) and Giunta and Trivieri (2007) find evidence showing that firms that export are more likely to use ICT. Similarly, foreign-owned firms are more likely to be early adopters of new technology as well as potentially important channels of new technology diffusion (Keller, 2004; Narula and Zanfei, 2005). 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.

*Epidemic effects* affecting the adoption of new technologies are linked to the 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. Hence, information spillover effects from interactions among firms may be important for the adoption of ICT. Baptista (2000) finds that, in

<sup>3</sup> The intensity of ICT use is measured by two variables: the number of ICT elements adopted and the share of employees using the Internet.

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 foster the adoption of new technology. Moreover, there is evidence suggesting that technology diffusion is geographically localized and information spillovers decline as distance between firms increases (Jaffe *et al.*, 1993; Keller, 2002).

Another dimension of epidemic effects 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). At the firm-level, networks may manifest in multi-unit firms.

In contrast to a well-established theoretical literature on the diffusion of new technologies, empirical evidence about the diffusion of ICT is scarce and inconclusive. With the exception of Hollenstein (2004) and Battisti *et al.* (2007) most of existing empirical studies (Fabiani *et al.*, 2005; Jeon *et al.*, 2006; Bayo-Moriones and Lera-López, 2007; Giunta and Tevieri, 2007) do not test hypotheses derived from theory and do not distinguish between inter- and intra-firm diffusion of ICT. Our article contributes to filling this gap. In particular, we estimate theory-based models and provide empirical evidence on the determinants of inter- and intra-firm diffusion of ICT across manufacturing firms in Ireland over the period 2001 to 2004. We also improve on the previous cross-section studies by using an unbalanced panel that allows us to explain the diffusion of ICT over time and to alleviate potential endogeneity arising from simultaneity and omitted variable bias.

### III. Data

Our data set is obtained by combining information from two sources. The first data source is the 'Survey on e-commerce and ICT' that has been conducted as part of a EU-wide effort to gain information on ICT

use since 2002 on an annual basis by the Central Statistics Office (CSO) in Ireland. 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 (CIP) which covers Irish manufacturing and is also collected by the CSO. The census contains information on turnover, exports, employment and earnings for all enterprises and local units with three or more employees.

The two data sets can be merged through the establishment identifier at the enterprise level.<sup>4</sup> The merged data set covers the period 2002–2004 for all variables. All information related to monetary values (e.g. transactions over the Internet as a share of turnover) in the survey on e-commerce and ICT is collected for the year prior to the survey year. As a result of this, information is available for the period 2001 to 2004. The combination of the two data sets covers roughly 40% 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, the panel is unbalanced, 23% of the firms are surveyed in all 3 years, 34% are surveyed in 2 years (not necessarily consecutive) and 43% of firms are surveyed in only 1 year.

The final working sample includes firms in the core manufacturing industries.<sup>5</sup> Further, we checked the data for outliers. We define as outliers observations where wages per employee are in the top or bottom 0.25% of the distribution and also observations that have changes in labour productivity, output growth, wages per employee, the share of sales due to online transactions, the share of clerical employees and the share of managerial and technical employees in the top and bottom 0.5% of the distribution. We omit all firms that have any 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.

<sup>4</sup> In this article, we use the terms enterprise and firm interchangeably.

<sup>5</sup> 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 this sector is dropped in several regressions due to the small number of observations together with the homogeneity of observations.



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					
	Firms with website		Firms that accept online orders		Employees using computers			Turnover due to online transactions		
	Obs.	%	Obs.	%	Obs.	Mean (%)	SD	Obs.	Mean (%)	SD
Year										
2002	1687	42.44	2143	10.78	1687	31.6	29.2	2143	1.19	6.72
2003	2169	47.44	1636	14.06	2050	33.9	29.6	1636	1.83	8.71
2004	1444	60.39	1236	15.13	1444	35.9	29.1	1236	2.08	9.25
Size										
<20	2922	36.82	2572	12.33	2871	30.8	29.5	2572	1.44	7.35
20–49	1235	56.84	1253	13.73	1202	33.3	27.8	1253	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	4475	45.23	4141	12.97	4381	30.9	28.3	4141	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	1370	54.01	1259	17.55	1331	42.6	32.7	1259	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	5300	49.38	5015	12.92	5181	33.7	29.4	5015	1.62	8.08

Notes: 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 III for more details on data from the survey on e-commerce and ICT).

#### 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 and whether the company accepts online orders. As shown in Table 1, by 2004, 60% of firms had a website. This share is higher for larger and for foreign-owned firms. The regional differences are not very large; the share of firms with a website is highest in the capital city region. The share of firms that accept online orders has increased over the analysed period to just over 15% 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. There is little difference between the shares of domestic and foreign-owned firms. Shares differ substantially across the different NUTS3 (Nomenclature of Territorial Units for Statistics) regions, with the greater Dublin area having the highest share of firms with online transactions.

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 due to online transactions including both transactions over the Internet (website, email) as well as transactions *via* EDI (*esale*). ICT use is higher in larger firms, and there is a clear time trend over the 3- or 4-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. Both indicators vary across regions; the regional variation is larger for the share of turnover due to online transactions. The dimensions presented in

Table 1 are not independent of one another: over 64% of foreign firms have 50 or more employees, while nearly 63% of domestic firms have less than 20 employees. While just over one-quarter of firms are located in the Dublin area, the firm size distribution is relatively similar across countries. Proportionately somewhat more foreign-owned firms are located in the Midwest and Southwest.

#### IV. Empirical Strategy and Model Specifications

Based on the discussion of the theory on new technology adoption in Section II, we model the adoption of ICT in firm  $i$ , industry  $j$ , region  $r$ , at time  $t$  ( $Y_{ijrt}$ ) as a function of rank effects and epidemic effects.<sup>6</sup> The basic model specification is as follows:

$$\begin{aligned} Y_{ijrt} = & \alpha + \beta_1 s2 + \beta_2 s3 + \beta_3 s4 + \beta_4 s5 + \beta_5 dlnto_{ijr,t-1} \\ & + \beta_6 age_{ijr,t-1} + \beta_7 multi_{ijr,t-1} + \beta_8 foreign_{ijr,t-1} \\ & + \beta_9 \ln wpe_{ijr,t-1} + \beta_{10} mantech_{ijr,t-1} \\ & + \beta_{11} clerical_{ijr,t-1} + \beta_{12} exint_{ijr,t-1} + \beta_{13} conc_{jt,t-1} \\ & + \beta_{14} epid\_indreg_{jr,t-1} + \beta_{15} epid\_ind_{jr,t-1} + \lambda_j \\ & + \lambda_r + \lambda_t + \varepsilon_{ijrt} \end{aligned} \quad (1)$$

##### Rank effects

We group firms into five size classes: firms with less than 20 employees (s1), firms with 20–49 employees (s2), firms with 50–249 employees (s3), firms with 250–499 employees (s4) and firms with 500 and more employees (s5) and treat the smallest firms as the reference group. Assuming that large firms are early adopters of ICT or use it more intensively, we expect positive coefficients  $\beta_1, \beta_2, \beta_3, \beta_4$  on the firm size dummies.

Further, rank effects include *output growth* ( $dlnto$ ), *firm age* ( $age$ ), a dummy variable which indicates whether a firm is a *multi-plant* firm ( $multi$ ) and a dummy for foreign ownership ( $foreign$ ). 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. While we expect to find  $\beta_5 > 0$ , the sign for  $\beta_6$  is ambiguous: 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.

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. A similar argument applies to foreign-owned firms.

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 ( $exint$ ) is included as a measure of international competitiveness. Firms that export may also find it easier to communicate with customers abroad using ICT. We expect ICT adoption and diffusion to be positively associated with export intensity. In addition, to proxy the effect of *competition* in the domestic market 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 using data on turnover ( $to$ ) as follows:

$$conc_{jt} = \sum_j (ms_{ijt})^2, \quad \text{where } ms_{ijt} = \frac{to_{ijt}}{\sum_i to_{jt}} \quad (2)$$

If the parameters  $\beta_1 - \beta_{13}$  are significantly different from zero, the hypothesis of the absence of rank effects can be rejected.

##### Epidemic effects

Spillover effects from interactions between firms are likely to be important determinants of ICT adoption at the firm level. 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  $t$  ( $epid\_ind_{\bar{r}t}$ ). The two variables are calculated as follows:

$$epid\_indreg_{jrt} = \frac{X_{jrt}^a}{X_{jrt}} \quad (3)$$

and

$$epid\_ind_{\bar{r}t} = \frac{X_{jt}^a - X_{jrt}^a}{X_{jt} - X_{jrt}} \quad (4)$$

where  $X_{jrt}^a$  denotes enterprises that are using ICT in industry  $j$ , region  $r$  at time  $t$  and  $X_{jrt}$  is the total

<sup>6</sup> We are unable to identify stock and order effects as our data set does not contain the initial adoption dates.

number of enterprises in industry  $j$ , region  $r$  at time  $t$ . 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*). If  $\beta_{14}$  and/or  $\beta_{15}$  are significantly different from zero, the hypothesis of the absence of epidemic learning effects can be rejected.

We control for unobserved industry-, region- and time-specific effects:  $\lambda_j$ ,  $\lambda_r$ ,  $\lambda_t$ , respectively, are dummy variables for 20 NACE (Nomenclature générale des Activités économiques dans les Communautés Européennes) 2-digit industries, eight 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 binary indicators of inter-firm ICT adoption as it is the case with *web* and *ns*. We further estimate a bivariate probit model for *web* and *ns* assessing firms' propensities to have both a website and to accept online sales.

In the case of intra-firm ICT adoption, the dependent variables are continuous (*empucomp*, *esale*) and they take values between 0 and 1. While these models could be estimated using Ordinary Least Squares (OLS), there is no guarantee that the predicted values will lie between 0 and 1. Using the log-odds, transformation would transform the observations to range over all real numbers, thus allowing OLS estimation. However, this transformation still requires the use of *ad hoc* transformations to handle data at the extreme values of zero and one. While few observations take on value 1, we have many observations that are zero. We therefore prefer to use the fractional probit model as proposed by Papke and Wooldridge (1996).

For a number of explanatory variables it might be the case that the firm's decision on their level is not exogenous to its decision on ICT adoption or the

intensity of ICT use. In order to reduce biases from potential endogeneity, all regressors are lagged by 1 year with respect to the dependent variable.<sup>7</sup> Ideally, we would also like to control for firm fixed effects; however, this is not an appealing option as only a nonrepresentative and highly homogenous sample of around 20% of firms is observed in all years. Finally, in all our regressions, the SEs are adjusted for clustering at the firm level.

## V. Empirical Results

The estimates for whether firms have a website are shown in the left half of Table 2. The models presented in the first two columns are estimated for all firms jointly. In the second column, the epidemic effects are added.

The results indicate that all firm size groups are more likely to have a website compared to firms with less than 20 employees. Further, our results indicate that fast-growing and younger firms are more likely to have a website. The human capital and employee composition variables (average wage per employee, share of managerial and technical employees and share of clerical employees) have a positive effect on a firm's propensity to have a website. Exposure to foreign markets as measured by the export intensity has a positive impact on the probability of a firm to have a website. The dummy for foreign ownership indicates that there are no significant differences between the domestic and foreign-owned firms.

There is no evidence of geographic (location) effects on the probability of having a website. The time dummies are significant, indicating a positive time trend in the adoption of websites. The industry dummies are jointly significant. **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.**

The right half of Table 2 shows the estimates for a firm's propensity to accept orders online. There is no evidence of size effects or effects from other firm characteristics; only the share of clerical employees has a positive impact on the propensity of a firm to

<sup>7</sup> We are able to do this without losing another year of our short panel because the explanatory variables come from the CIP that collects information for all firms with more than three employees in every year. For those epidemic effects based on the share of firms with a website, we are able to use lags without losing a year of data, 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.



Table 2. Determinants of inter-firm ICT adoption: probit estimates

	Firm's propensity to have a website		Firm's propensity to accept online orders	
Rank effects				
s2 (20–49)	0.154 (0.027)***	0.157 (0.027)***	−0.008 (0.016)	−0.006 (0.016)
s3 (50–249)	0.252 (0.032)***	0.246 (0.033)***	−0.014 (0.021)	−0.013 (0.020)
s4 (250–499)	0.317 (0.057)***	0.261 (0.068)***	−0.045 (0.033)	−0.048 (0.030)
s5 (500+)	0.360 (0.074)***	0.336 (0.080)***	−0.019 (0.050)	−0.031 (0.041)
<i>dlnto</i>	0.055 (0.026)**	0.054 (0.026)**	0.016 (0.017)	0.015 (0.017)
<i>age</i>	−0.001 (0.001)	−0.001 (0.001)*	0.001 (0.000)	0.000 (0.000)
<i>multi</i>	0.091 (0.072)	0.074 (0.073)	0.024 (0.040)	0.032 (0.040)
<i>foreign</i>	−0.055 (0.041)	−0.069 (0.042)	−0.025 (0.022)	−0.023 (0.020)
<i>lnwpe</i>	0.162 (0.033)***	0.159 (0.033)***	−0.002 (0.019)	0.001 (0.019)
<i>mantech</i>	0.437 (0.097)***	0.380 (0.097)***	0.077 (0.050)	0.065 (0.048)
<i>clerical</i>	0.637 (0.089)***	0.526 (0.092)***	0.107 (0.045)**	0.085 (0.043)**
<i>exint</i>	0.155 (0.043)***	0.117 (0.044)***	0.077 (0.025)***	0.063 (0.023)***
<i>conc</i>	0.257 (0.133)*	0.044 (0.149)	0.014 (0.081)	−0.021 (0.077)
Epidemic effects				
<i>epid_indreg_web</i>		0.730 (0.064)***		
<i>epid_ind_web</i>		−0.109 (0.101)		
<i>epid_indreg_ns</i>				0.283 (0.038)***
<i>epid_ind_ns</i>				0.120 (0.074)
Other controls				
Border	0.013 (0.038)	0.059 (0.038)	−0.039 (0.018)**	−0.033 (0.018)*
Midlands	−0.028 (0.053)	0.018 (0.054)	−0.072 (0.017)***	−0.058 (0.019)***
West	0.026 (0.042)	0.059 (0.042)	−0.019 (0.022)	−0.016 (0.021)
Mideast	−0.026 (0.041)	0.008 (0.042)	−0.045 (0.019)**	−0.039 (0.019)**
Midwest	−0.031 (0.046)	0.012 (0.046)	−0.044 (0.019)**	−0.032 (0.020)
Southeast	−0.036 (0.037)	0.004 (0.038)	−0.065 (0.016)***	−0.055 (0.016)***
Southwest	0.017 (0.037)	0.019 (0.038)	−0.056 (0.016)***	−0.048 (0.016)***
2003	0.053 (0.011)***	0.033 (0.012)***	0.035 (0.011)***	0.035 (0.012)***
2004	0.130 (0.016)***	0.100 (0.018)***	0.048 (0.014)***	0.029 (0.014)**
Ind $\chi^2(p)$	44.76 (0.00)	32.14 (0.03)	46.02 (0.00)	17.28 (0.57)
Obs./firms	4859 2625	4859 2625	3993 2298	3993 2298
log <i>L</i>	−2856.8	−2734.0	−1474.2	−1440.9
$\chi^2$	531.9	604.0	130.1	204.5
<i>R</i> <sup>2</sup> pseudo	0.15	0.19	0.05	0.08

Notes: Estimated marginal effects and robust SEs adjusted for clustering at the firm level in parentheses. A constant is included in all regressions. All explanatory variables are lagged by 1 year with respect to the dependent variable. Omitted categories are: size, s1 (3–19); region, Dublin; year, 2002. Ind  $\chi^2(p)$  –  $\chi^2$ -test for the joint significance of the nonreported NACE 2-digit industry dummies (*p*-value). Industry-year cells with only one firm are not included.

\*\*\*, \*\* and \* indicate significance at 1, 5 and 10%, respectively.

accept online orders. An important driver is again exposure to export markets. This may reflect that firms that export abroad need to communicate with customers in far-away places, which may be easier with ICT. There is also evidence that exporting is closely correlated with productivity.<sup>8</sup> As virtually all foreign-owned firms in Ireland export a substantial share of their turnover, the variation in this variable comes mostly from the domestic firms, both in terms of their propensity to export and their export intensity. This may indicate that only the more

productive domestic firms are also more likely to accept online orders.<sup>9</sup>

There are significant location effects, in that firms that are located outside the capital city region are less likely to accept orders online. The industry dummies are jointly significant when we do not include the epidemic effects. 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.

<sup>8</sup> There is evidence for Ireland and a number of other countries that more productive firms are more likely to select into exporting both internationally (The International Study Group on Exports and Productivity, 2008).

<sup>9</sup> When we estimate these regressions for the subsample of foreign-owned firms, the coefficient on the export intensity is not significant.

**Table 3. Number of firms with a website and online orders**

		Firm accepts online orders		
		0	1	Sum
Firm has a website	0	1303	104	1407
	1	1174	286	1460
	Sum	2477	390	2867

We further examine to what extent firms use both a website and online orders. Table 3 shows the distribution of firms in four groups: firms using a website and accepting online orders; firms accepting online orders but without a website (this is not a contradiction as online orders include email and EDI); firms with a website but not accepting online orders; and firms that do not accept online orders and do not have a website.

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. More than half of the firms in the sample have a website, but only about 13% of firms accept online orders and only about 10% of firms have both a website and accept online orders.

The estimates of the bivariate probit model are shown in Table 4. We restrict attention to the most zealous adopters, i.e. firms that have a website and accept online orders and to the complete nonadopters, i.e. firms that do not have a website and do not accept online orders. Firms with a large share of clerical employees, firms with high 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, i.e. to have a website and accept online orders.

The second column of Table 4 shows the determinants of not having a website and also not accepting online orders. All firm size groups with more than 20 employees have a lower propensity to fall into this group than firms with less than 20 employees. Firms with high human capital intensities are less likely to fall into this group; the same is true for firms with high export intensities. The negative coefficients on both measures of epidemic effects suggest that this group of mainly small, nonexporting and low human capital intensity firms might be missing out on the ICT diffusion path.

**Table 4. Determinants of inter-firm ICT adoption: bivariate probit estimates of having a website and accepting online orders**

	<i>ns</i> = 1, <i>web</i> = 1	<i>ns</i> = 0, <i>web</i> = 0
Rank effects		
<i>s2</i> (20–49)	0.002 (0.014)	–0.131 (0.032)***
<i>s3</i> (50–249)	–0.006 (0.018)	–0.232 (0.039)***
<i>s4</i> (250–499)	–0.035 (0.032)	–0.228 (0.089)***
<i>s5</i> (500+)	–0.023 (0.040)	–0.263 (0.104)**
<i>dlnto</i>	0.014 (0.015)	–0.029 (0.036)
<i>age</i>	0.000 (0.000)	0.001 (0.001)
<i>multi</i>	0.009 (0.040)	–0.095 (0.091)
<i>foreign</i>	–0.005 (0.018)	0.076 (0.049)
<i>lnwpe</i>	0.018 (0.017)	–0.128 (0.041)***
<i>mantech</i>	0.039 (0.044)	–0.382 (0.121)***
<i>clerical</i>	0.105 (0.042)**	–0.504 (0.112)***
<i>exint</i>	0.049 (0.020)**	–0.166 (0.053)***
<i>conc</i>	–0.003 (0.072)	–0.128 (0.190)
Epidemic effects		
<i>epid_indreg_ns</i>	0.252 (0.035)***	–0.166 (0.087)*
<i>epid_ind_ns</i>	0.093 (0.065)	–0.039 (0.161)
<i>epid_indreg_web</i>	0.086 (0.032)***	–0.640 (0.078)***
<i>epid_ind_web</i>	0.011 (0.053)	0.150 (0.131)
Other controls		
Border	–0.011 (0.017)	–0.038 (0.046)
Midlands	–0.064 (0.013)***	–0.011 (0.068)
West	–0.019 (0.019)	–0.011 (0.052)
Mideast	–0.026 (0.017)	0.015 (0.050)
Midwest	–0.012 (0.020)	0.019 (0.057)
Southeast	–0.039 (0.014)***	0.032 (0.046)
Southwest	–0.033 (0.015)**	0.028 (0.047)
2003	0.029 (0.010)***	–0.039 (0.016)**
2004	0.028 (0.013)**	–0.088 (0.024)***
Ind $\chi^2(p)$	56.54	(0.03)
Obs./firms	2867/1667	
log <i>L</i>	–2596.0	
$\chi^2$	603.3	

Notes: Estimated marginal effects and robust SEs adjusted for clustering at the firm level in parentheses. A constant is included in all regressions. All explanatory variables are lagged by 1 year with respect to the dependent variable. Omitted categories are: size, *s1* (3–19); region, Dublin; year, 2002. Ind  $\chi^2(p)$  –  $\chi^2$ -test for the joint significance of the nonreported NACE 2-digit industry dummies (*p*-value). Industry-year cells with only one firm are not included. \*\*\*, \*\* and \* indicate significance at 1, 5 and 10% levels, respectively.

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 as shown in the left half of Table 5. Intermediate-size firms appear to be somewhat less likely to have a high share of employees using computers than the group of firms with less than 20 employees. Younger firms and foreign-owned firms have a higher propensity to have a high share of

Table 5. Determinants of intra-firm ICT diffusion: fractional probit estimates

	Share of employees using computers		Share of turnover due to online transactions	
Rank effects				
s2 (20–49)	−0.022 (0.012)*	−0.020 (0.012)	−0.005 (0.003)*	−0.004 (0.002)*
s3 (50–249)	−0.023 (0.015)	−0.026 (0.015)*	0.001 (0.004)	0.001 (0.003)
s4 (250–499)	0.023 (0.027)	0.009 (0.026)	0.004 (0.012)	0.002 (0.009)
s5 (500+)	0.017 (0.038)	0.004 (0.038)	0.018 (0.022)	0.012 (0.016)
<i>dlnto</i>	−0.008 (0.014)	−0.010 (0.014)	0.003 (0.004)	0.003 (0.004)
<i>age</i>	−0.001 (0.000)**	−0.001 (0.000)***	0.000 (0.000)	0.000 (0.000)
<i>multi</i>	0.008 (0.025)	−0.001 (0.024)	−0.008 (0.003)**	−0.007 (0.003)***
<i>foreign</i>	0.079 (0.018)***	0.074 (0.018)***	−0.002 (0.004)	−0.001 (0.003)
<i>lnwpe</i>	0.119 (0.017)***	0.117 (0.017)***	0.000 (0.004)	0.001 (0.003)
<i>mantech</i>	0.427 (0.050)***	0.390 (0.050)***	0.016 (0.009)*	0.013 (0.008)
<i>clerical</i>	0.565 (0.041)***	0.497 (0.041)***	0.003 (0.007)	0.001 (0.007)
<i>exint</i>	0.050 (0.018)***	0.029 (0.018)	0.017 (0.004)***	0.013 (0.003)***
<i>conc</i>	0.113 (0.054)**	−0.029 (0.057)	0.004 (0.017)	−0.002 (0.014)
Epidemic effects				
<i>epid_indreg_web</i>		0.109 (0.027)***		
<i>epid_ind_web</i>		0.282 (0.046)***		
<i>epid_indreg_ns</i>				0.045 (0.008)***
<i>epid_ind_ns</i>				0.012 (0.012)
Other controls				
Border	−0.056 (0.016)***	−0.052 (0.016)***	0.003 (0.005)	0.004 (0.004)
Midlands	−0.048 (0.020)**	−0.043 (0.020)**	−0.006 (0.004)	−0.003 (0.004)
West	0.009 (0.021)	0.010 (0.021)	−0.003 (0.003)	−0.002 (0.003)
Mideast	−0.020 (0.019)	−0.014 (0.019)	−0.003 (0.004)	−0.001 (0.003)
Midwest	−0.018 (0.019)	−0.018 (0.019)	−0.005 (0.003)*	−0.003 (0.003)
Southeast	−0.041 (0.017)**	−0.036 (0.017)**	−0.004 (0.004)	−0.004 (0.003)
Southwest	−0.014 (0.016)	−0.020 (0.016)	−0.002 (0.004)	−0.001 (0.004)
2003	0.013 (0.007)*	0.001 (0.007)	0.006 (0.002)***	0.006 (0.002)***
2004	0.006 (0.008)	−0.014 (0.008)*	0.006 (0.002)***	0.003 (0.002)
Ind $\chi^2(p)$	242.15 (0.00)	172.76 (0.00)	37.21 (0.01)	33.08 (0.02)
Obs./firms	4742 2625	4742 2625	3993 2298	3993 2298
log <i>L</i>	−2045.4	−2028.8	−279.1	−266.9
$\chi^2$	1370.8	1452.2	118.2	146.9

Notes: Estimated marginal effects and robust SEs adjusted for clustering at the firm level in parentheses. A constant is included in all regressions. All explanatory variables are lagged by 1 year with respect to the dependent variable. Omitted categories are: size, s1 (3–19); region, Dublin; year, 2002. Ind  $\chi^2(p)$  –  $\chi^2$ -test for the joint significance of the nonreported NACE 2-digit industry dummies (*p*-value). Industry-year cells with only one firm are not included.

\*\*\*, \*\* and \* indicate significance at 1, 5 and 10% levels, respectively.

employees using computers. Not surprisingly, there are strong positive effects from the average wage per employee and from the share of managerial and technical employees as well as from the share of clerical employees. The export intensity only matters when the spillover effects are not included. There are some location effects; also here firms in some regions have a lower propensity to have a high share of employees using computers than firms located in the Dublin area. The share of employees using computers is positively associated with proximity to firms in an industry and region where a high share of firms have a website and with being in the same industry but not the same region where a high share of firms have a website. 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 computerized production processes than others.

The right half of Table 5 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 are significant. The two main determinants of a firm's propensity to have a high share of turnover due to online transactions are export intensity and multi-unit status. Being part of a multi-unit enterprise has a negative effect 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 nonmetallic 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. 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.

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% of all enterprises in the data set 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.<sup>10</sup>

## VI. Concluding Remarks

This article contributes to the empirical analysis of determinants of ICT diffusion. We estimate a model derived from the theory of new technology diffusion and test for rank and epidemic effects. In comparison to existing cross-section studies, we estimate an improved econometric model using a novel firm-level panel data set of the Irish manufacturing sector. In particular, we provide empirical evidence on factors driving inter-firm ICT adoption (the usage of websites and online orders) and intra-firm ICT use (the share of employees using computers and the share of turnover due to online transactions).

Our results support the hypothesized rank and epidemic effects. We find 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 region. The determinants of inter- and intra-firm adoption of ICT are broadly similar with the exception of the effect of firm size and

foreign ownership. It appears that while larger firms are more likely to be earlier adopters than small firms, small firms use ICT more intensively than medium-sized firms. This result is similar to findings reported by Hollenstein (2004) and Battisti *et al.* (2007). While the propensity to adopt ICT is not significantly different in foreign-owned firms when compared to domestic firms, foreign-owned firms use ICT more intensively than domestic firms. This result is similar to findings of Teo and Ranganathan (2004) in the case of the adoption of business-to-business e-commerce in Singapore and Barbosa and Faria (2008) in the case of advanced manufacturing technologies in Portugal.

With respect to inter-firm adoption of ICT, we find that the propensity to have a website is higher for larger, younger, fast-growing, skill-intensive and export-intensive firms. Similar results using different indicators for ICT adoption are found for the UK (Battisti *et al.*, 2007), Switzerland (Hollenstein, 2004; Battisti *et al.*, 2007), Italy (Fabiani *et al.*, 2005; Giunta and Trivieri, 2007) and Spain (Bayo-Moriones and Lera-López, 2007).

While firm characteristics matter most for a firm's propensity to have a website and for the share of employees using computers, for a firm's propensity to accept online orders and for its share of turnover due to online transactions, organizational factors such as being part of a multi-plant enterprise and the share of clerical employees in total employees matter more. Exposure to export markets is an important positive influence for all our measures of inter- and intra-firm ICT diffusion. This finding may capture productivity differences closely associated with exporting as well as ICT facilitating communication between partners in different countries. This result is stronger compared to other studies (Hollenstein, 2004; Giunta and Trivieri, 2007).

The regional variation in ICT adoption and use in our sample may reflect supply effects related to the uneven provision of ICT infrastructure such as broadband access. Epidemic learning or information spreading effects largely at the regional level are crucial in enhancing both the adoption and the intensity of ICT use.

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<sup>10</sup> Results are not reported but are available from the authors on request.



confidential micro data sets on the premises of the CSO is provided for in the Statistics Act 1993. The use of CSO data in this work does not imply the endorsement of the CSO in relation to the interpretation or analysis of the data. This work uses research data sets which may not exactly reproduce statistical aggregates published by the CSO. We are grateful to George Hussey, Don Forde and Richard McMahon from the CSO of Ireland for valuable data-related assistance. The article has been screened by the CSO to ensure that no confidential information is revealed. Financial support from the EU's RTD Sixth Framework Programme (contract no. CIT5-028818) is gratefully acknowledged. We thank Frances Ruane, John Fitz Gerald, Seán Lyons, Frank Barry, Roberta Capello, Holger Görg, Mary O'Mahony, Paul Gorecki, the editor Mark Taylor, an anonymous referee and participants at research seminars at the Economic and Social Research Institute in Dublin, Bocconi University in Milan, Università delle Marche at Ancona, Centre for European Economics Research (ZEW) in Mannheim, the annual conference of the Royal Economic Society at Warwick University and the annual congress of the European Economic Association in Barcelona for helpful comments and suggestions.

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**Appendix 1****Description of variables and summary statistics**

Variable	Description	Source	Mean	SD
<i>web</i>	1 if firm has a website; 0 otherwise	ECS	0.494	0.500
<i>ns</i>	1 if firm accepts online orders; 0 otherwise <sup>a</sup>	ECS	0.129	0.335
<i>empucomp</i>	Share of employees using a computer	ECS	0.337	0.294
<i>esale</i>	Share of turnover due to transactions over the Internet including website, email and EDI – based mainly on the ECS, information from the CIP is used to fill in missing years where possible and for consistency checks between the two data sets	ECS + CIP	0.016	0.081
<i>s1–s5</i>	Firm size groups based on the number of persons engaged	CIP	55.47 <sup>b</sup>	154.85 <sup>b</sup>
<i>dlnto</i>	Turnover growth rate <sup>c</sup>	CIP	0.016	0.301
<i>age</i>	Firm age (earliest year of incorporation recorded is 1900)	CIP	17.51	17.65
<i>multi</i>	1 if enterprise has more than one plant; 0 otherwise	CIP	0.033	0.178
<i>foreign</i>	1 if enterprise's ultimate beneficial foreign owner is located abroad; 0 otherwise	CIP	0.156	0.363
<i>lnwpe</i>	Wages per employee <sup>c</sup>	CIP	3.045	0.394
<i>mantech</i>	Share of managerial and technical employees	CIP	0.145	0.127
<i>clerical</i>	Share of clerical employees	CIP	0.131	0.138
<i>exint</i>	Share of turnover exported	CIP	0.245	0.362
<i>conc</i>	Herfindahl–Hirschman index computed at 3-digit NACE level	CIP	0.072	0.121
<i>epid_indreg_web</i>	Share of firms with a website in all firms in the same 2-digit NACE sector and NUTS3-region	CIP	0.485	0.242
<i>epid_ind_web</i>	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
<i>epid_indreg_ns</i>	Share of firms accepting online orders in the same 2-digit NACE sector and NUTS3-region	ECS + CIP	0.118	0.171
<i>epid_ind_ns</i>	Share of firms accepting online orders in the same 2-digit NACE sector but not in the same NUTS3-region	ECS + CIP	0.113	0.095

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

<sup>a</sup>Replaced to 1 if equal to zero and e-sale had positive value.

<sup>b</sup>Refers to the number of persons engaged.

<sup>c</sup>Monetary values expressed in €1000 in constant 2000 prices. Turnover data are deflated using the sector level producer price index reported by the CSO; wage data are deflated using the consumer price index.