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Are ICT Users More Innovative? An Analysis of ICT-Enabled Innovation in OECD Firms

by
Vincenzo Spiezia*

The aim of this study is to assess the effects of information and communications technologies (ICTs) on firms' capabilities to innovate in a selection of OECD countries. Our findings support the hypothesis that ICTs act as an enabler of innovation, particularly for product and marketing innovation, in both manufacturing and services. However, we did not find any evidence that ICT use increases the capability of a firm to co-operate, to develop innovation in-house or to introduce products new to the market. These results suggest that ICTs enable firms to adopt innovation but they do not increase their "inventive" capabilities.

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Keywords: ICT, Innovation, micro data, Conditional Maximum Likelihood

* Vincenzo Spiezia (vincenzo.spiezia@oecd.org), Economic Analysis and Statistics Division, Directorate for Science, Technology and Industry. The opinions expressed in this article are those of the author and do not necessarily reflect those of the OECD or its member countries.

The aim of this study is to assess the effects of information and communications technologies (ICTs) as an enabler of innovation in a selection of OECD countries. Innovation refers to product, process, organisational and marketing innovations (see OECD/Eurostat, *Oslo Manual*, 2005).

ICTs have the potential to increase innovation by speeding up the diffusion of information, favouring networking among firms, enabling closer links between businesses and customers, reducing geographic limitations and increasing efficiency in communication.

Previous analysis confirms that ICTs play an important role in enabling business innovation, *e.g.* Brynjolfsson and Hitt, 2000; Gago and Rubalcaba, 2007; Crespi *et al.*, 2007; Eurostat, 2008; Van Leeuwen, 2008; Polder *et al.*, 2009. These studies, however, differ as regards their methodology and country coverage or they do not focus on the link between ICT use and innovation.

The main contribution of the present study is to address the effects of ICT use on innovation in a cross-country perspective based on a comparable data set and according to a common methodology.

The study is based on two statistical sources: the ICT Business Survey and the Innovation Survey. Information from these two surveys has been linked at the firm level. Due to confidentiality reasons, the analysis has been carried out by a network of national researchers with access to the micro-data, based on the same econometric model set by the OECD.

The network consisted of 14 researchers[1] from nine countries: Canada, Italy, Luxembourg, the Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom.

We adopted a simple approach, which is to test whether the expected effects of ICT use on innovation are supported by the data. The research, therefore, consists of a set of 19 testable hypotheses about the effects of ICT use on innovation, grouped under three themes:

- Innovation capabilities
- Innovation trajectories
- Co-operation in innovation.

As innovation is considered a key determinant of business productivity, the findings of this study would be relevant for businesses and policy makers alike.

The study is organised as follows. Section 1 summarises the main findings by previous studies. Section 2 introduces the definitions of innovation and ICT use. Section 3 presents the dataset used in this study while Sections 4 and 5 discuss the research questions and the methodology, respectively. The main findings are discussed in Section 6. Finally, Section 7 draws the main conclusions and makes suggestions for further work.

1. Previous findings

Business innovation is regarded as a key determinant of both individual business success and national economic growth. At the micro level, business innovation has the potential to increase consumer demand through improved product or service quality and simultaneously decrease production costs. More importantly, strong business innovation at a macro level increases multifactor productivity thus lifting international competitiveness, economic growth and real per capita incomes. Therefore, it is of great interest to businesses and policy makers alike to identify those factors which stimulate innovation and to understand how these factors interact.

ICT is a valuable source of business innovation because it provides substantial efficiency gains. As Koellinger (2005) puts it "ICT makes it possible to reduce transaction costs, improve business processes, facilitate co-ordination with suppliers, fragment processes along the value chain (both horizontally and vertically) and across different geographical locations, and increase diversification."

Each of these efficiency gains provides an opportunity for innovation. For example, IT automated system links lead to more streamlined business processes and allow staff to be more responsive to emerging customer needs. Similarly, technologies which allow staff to effectively communicate and collaborate across wider geographic areas will encourage strategies for less centralised management, and more flexible external relations, all of which involve different types of innovative activity.

Gretton, Gali and Parham (2004) have suggested two additional reasons why business use of ICT encourages innovative activity. Firstly, ICT is a "general purpose technology" which provides an "indispensable platform" upon which further productivity-enhancing changes, such as product and process innovations, can be based. For example, a business which establishes a web presence sets the groundwork from which process innovations, such as electronic ordering and delivery, can be easily developed. In this way, adopting general purpose ICT makes it relatively easier and cheaper for businesses to develop innovations.

Secondly, the spillover effects from ICT usage, such as network economies, can be sources of productivity gains. For example, staff in businesses which have adopted broadband Internet are able to collaborate with wider networks of academics and international researchers more closely on the development of innovations and keep abreast of current consumer trends. These are spillover benefits because the R&D efforts of other researchers in the collaborative group can be appropriated by all.

Information and communication technologies can also be seen as a source of innovation because they enable closer links between businesses, their suppliers, customers, competitors and collaborative partners. These agents are all understood to be important sources of ideas for innovation. By enabling closer communication and collaboration, ICT assists businesses to be more responsive to innovation opportunities and provides significant efficiency gains. For example, having ICTs such as broadband Internet, web presence and automated system linkages, helps businesses to keep up with customer trends, monitor competitor's actions and get rapid users' feedback, thereby assisting them to exploit opportunities for all types of innovation.

Previous econometric analysis confirms that ICTs play an important role in enabling business innovation. Gago and Rubalcaba (2007) find that businesses that invest in ICT,

particularly those which regard their investment as very important, or strategically important, are significantly more likely to engage in services innovation.

The Eurostat ICT impacts project (Eurostat, 2008) reveals that – on average – ICT usage is positively related to firm performance. The strength of these results varies over countries, however, and it also appears that the benefits of different types of ICT usage are industry specific. Van Leeuwen (2008) shows that e-sales and broadband use affect productivity significantly through their effect on innovation output. Broadband use, however, only has a direct effect on productivity if R&D is not considered as an input to innovation.

This approach is further developed by Polder *et al.* (2009). Their study finds out that ICT investment is important for all types of innovation in services, while it plays a limited role in manufacturing, being only marginally significant for organisational innovation.

Another line of literature points to the importance of ICT for organisational innovation (see Brynjolfsson and Hitt, 2000 for a survey). Case studies reveal that the introduction of information technology is combined with investment in intangible assets and a transformation of the firm and of its relation with suppliers and customers. Electronic procurement, for instance, increases the control of inventories and decreases the costs of co-ordinating with suppliers, and ICT offers the possibility for flexible production: just-in-time inventory management, integration of sales with production planning, *etc.* A lack of proper control for intangible assets is seen as a possible candidate for explaining the differences in productivity growth that are observed between Europe and the United States.

The available econometric evidence at the firm level shows that a combination of investment in ICTs and changes in organisations and work practices facilitated by these technologies contributes to firms' productivity growth. Crespi *et al.* (2007) use CIS data for the United Kingdom and find a positive effect of the interaction between IT and organisational innovation on firm performance. They also find a significant effect of competition on organisational innovation.

These results confirm recent findings that ICTs are an important enabler for capturing and processing knowledge in the innovation through-put stage. In addition, the observed industry differences suggest that new ICT applications, such as broadband connectivity and e-commerce, are more important in services than in manufacturing.

This paper makes a number of contributions to the existing literature.

First, while most studies investigate the effects of ICT use on innovation in one country, this paper provides evidence for a larger set of countries based on a common methodology.

Second, different studies adopt different measures of ICT use but they do not provide justification for preferring one measure over the other. This paper, on the contrary, compares alternative measures of ICT use and their statistical relationship to innovation.

Third, ICTs are analysed as an enabler of innovation, so that the intensity of ICT use and the introduction of an innovation are modelled as the result of a simultaneous choice by the firms.

Finally, the paper directly addresses the issue of endogeneity of ICT use, which is generally neglected in previous studies.

2. Definitions

2.1. Innovation

The *Oslo Manual* defines an "innovation" (OECD/Eurostat 2005, p. 46) as:

"*... the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations*."

A product innovation is the introduction of a good or service that is significantly improved with respect to its characteristics or intended uses and includes significant improvements in technical specifications, components and materials, incorporated software and user friendliness or other functional characteristics (*Oslo Manual* 2005, p. 48). Design changes which do not involve a significant change in the product's functional characteristics or intended use, such as a new flavour or colour option, are not product innovations. Product innovations in services can include significant improvements in how the product is provided, such as home pick-up or delivery services, or other features which improve efficiency or speed.

A process innovation is a new or significantly-improved production or delivery method, including significant changes in techniques, equipment and/or software (*Oslo Manual* 2005, p. 49). For example, introduction of a new automation method on a production line, or in the context of ICT, developing electronic system linkages to streamline production and delivery processes, are both process innovations. With respect to services, it is often difficult to distinguish a product and process innovation. The *Oslo Manual* (2005, p. 53) contains the following guidelines to distinguish the two types of innovation:

- If the innovation involves new or significantly-improved characteristics of the service offered to customers, it is a product innovation.
- If the innovation involves new or significantly-improved methods, equipment and/or skills used to perform the service, it is a process innovation.

An organisational or managerial innovation is the implementation of a new or significantly-improved method of the firm's business practices, workplace organisation or external relations. It requires more than mere organisational change or restructure. In fact, the organisational method must not have been previously used by the business and must be the result of strategic decisions taken by management (*Oslo Manual* 2005, p. 49). Examples include implementation of a new method for distributing responsibilities and decision-making among employees, decentralising group activity, developing formal or informal work teams, new types of external collaboration with research organisations or the use of outsourcing or sub-contracting for the first time (*Oslo Manual* 2005, p. 52).

A marketing innovation is the implementation of a new or significantly-improved marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing. The marketing method must not have been previously used by the firm and must be part of a new marketing concept or strategy representing a significant departure from the firm's existing methods (*Oslo Manual* 2005, p. 50).

The OECD has recommended that countries collect qualitative survey data on innovation activities. These qualitative measures of innovation are more encompassing than traditional innovation measures. For example, measures such as R&D expenditure per employee, patents received or sales derived from new products will not encompass all the innovative efforts of a business and will be biased towards particular types of innovation.

2.2. ICT use

The definition of ICT use by firm is less clear-cut and codified. Computer use does not seem a relevant criterion any longer, as virtually all firms use the computer. The use of a computer network seems to be a more appropriate measure of ICT use, although the information technology in use (*e.g.* Extranet, WAN, *etc.*) may have different effects on innovation.

Given the dominance of IP-based networks, one may reasonably argue that Internet use, particularly broadband Internet, is what makes a firm an ICT user. Some previous studies (Eurostat, 2008) have pointed out that the percentage of broadband connected employees is a better measure of the intensity of ICT use by firms.

As there is no unique measure of the intensity of ICT use, we explored the correlation between the probability to innovate and a set of potential indicators for ICT use available from the ICT Business Surveys: the number of web facilities; the number of automatic IT links; the share of employees with a broadband connection to the Internet; the value of e-sale; the value of e-purchasing; the presence of a firm's web page; the first factor from a factor analysis of all the above indicators; the simple average of the above indicators.

The number of web facilities and the number of automatic IT links turned out to have the highest correlation to innovation in all countries. Therefore, our econometric analysis included either one of these two variables as a measure of the intensity of ICT use.

The number of web facilities is computed from the answers to the following questions ("Eurostat model for a Community Survey on ICT Usage and e-Commerce in Enterprises 2006"):

B9. Did the Web Site of your enterprise provide the following facilities during January 2006? (your enterprise *as provider* of internet services)		
	Yes	No
a) Marketing the enterprise's products	❒	❒
b) Facilitating access to produce catalogues and price lists	❒	❒
c) Providing after-sales support	❒	❒

Firms are asked to answer all questions with yes or no. Therefore, the indicator varies between 0 (firms have no web facilities) to 3 (firms have all web facilities).

The number of automatic IT links is based on the answers to the following questions from the same survey:

A9*. Did your enterprise's IT systems for managing orders link automatically with any of the following IT systems, during January 2006?		
	Yes	No
a) Internal system for re-ordering replacement supplies	❒	❒
b) Invoicing and payment systems	❒	❒
c) Your system for managing production, logistics or service operations	❒	❒
d) Your suppliers' business systems (for suppliers outside your enterprise group)	❒	❒
e) Your customers' business systems (for customers outside your enterprise group)	❒	❒

Firms are asked to answer all questions with yes or no. Therefore, the indicator varies between 0 (firms have no automatic IT link) to 5 (firms have all automatic IT links).

Strictly speaking, neither of these two indicators is a measure of the intensity of ICT use by firms. They are rather a measure of the sophistication or scope of ICT use. However, both indicators are correlated to the intensity of use. Adding a new web facility or a new automatic link to the firm's IT system is costly and a firm would not undertake such an investment if it did not use it.

Clearly, firms with the same automatic IT links or web facilities may use them differently and our indicators would not capture these differences. In addition, IT links and web facilities seem biased towards the use of ICTs for e-commerce and e-business but they may be a poorer proxy for other ICT-enabled activities relevant for innovation, *e.g.* communication.

Bearing these limitations in mind, in the rest of this study we will regard the number of web facilities and of automatic IT links as a measure of the intensity of ICT use by firms.

3. The dataset

The project relies on two statistical sources: 1. the ICT Business Survey; and 2. the Innovation Survey.

The ICT Business Survey follows the OECD Model Survey in virtually all OECD countries. Therefore, comparable statistics on ICT use in firms are easily available in all countries.

Innovation surveys, on the contrary, tend to be more country-specific. The Community Innovation Survey (CIS) is a noticeable exception, as the same questionnaire is submitted to firms in all EU countries participating in the survey. In general, however, the definitions of innovation comply with the recommendations of the *Oslo Manual* (OECD/Eurostat, 2005). This is the case for two non-EU countries included in this study: Canada and Switzerland.

The analysis of the ICT effects of innovation requires "linking" the ICT survey and the Innovation survey at the level of firm. Therefore, the sample for the analysis is limited to those firms that responded to both the ICT survey and the Innovation survey.

Table 1 shows the number and percentage of firms in the latest available Innovation survey that also responded to the ICT survey in the countries considered in the present study.

Table 1. **Number of firms that responded both to the ICT and the Innovation survey – latest year available**

			As a % of all firms in the Innovation Survey		
	Year	Total	Whole economy	Manufacturing	Services
Canada[1]	2007	488	7	7	–
Italy	2004	4 391	29	33	25
Ireland	2005	584	30	47	16
Luxembourg	2007	369	49	51	49
Netherlands	2007	3 549	61	61	60
Norway	2006	1 421	33	34	33
Portugal	2005	1 476	20	16	24
Spain	2006	4 570	14	13	15
Sweden	2006	561	17	14	20
Switzerland	2008	2 555	100	100	100
United Kingdom	2006	706	13	10	19

1. Imperfect match between ICT and Innovation surveys.

Table 1 shows that:

- In most countries, only a small percentage of firms in the Innovation survey also responded to the ICT survey. This percentage is particularly low for services. This raises an issue of representativeness of the joint ICT-Innovation sample, which is likely to be biased towards manufacturing industries and large firms.
- In many countries, the total number of firms in the joint ICT-Innovation sample is relatively small. This implies that the number of variables that we can consider in an econometric analysis is fairly limited.

The above limitations result from the survey design currently in place for most surveys in a large majority of countries. Traditionally, surveys have been designed to estimate representative "averages" for the population and for selected groups of the population. In order to reduce the burden on the respondents, samples for different surveys have been designed as to reduce overlapping or even to exclude it (*e.g.* the ICT survey and the CIS in France).

As the capability to analyse micro data increases, largely due to ICT, the survey design has to be reconsidered in order to facilitate data linking between different surveys *and/or* to merge questions from different survey – *e.g.* ICT and Innovation surveys – into the same one. Both strategies have significant implications in terms of costs for the Statistical Offices and burden for the respondents. Therefore, an assessment by the NSOs on how to meet the demand for micro data is becoming increasingly necessary.

The present analysis is based on data on manufacturing and services in all countries except Canada, where the matching between the ICT and Innovation surveys was possible only for firms in manufacturing due to the different statistical units used in the two surveys (firms for the ICT and establishment in the Innovation survey).

Box 1. **List of testable hypotheses by theme**

1. Innovation capabilities

Hypothesis 1:	The probability to innovate increases with the intensity of ICT use.
Hypothesis 1a:	The probability to introduce a new product increases with the intensity of ICT use.
Hypothesis 1a1:	The probability to introduce a new good increases with the intensity of ICT use.
Hypothesis 1a2:	The probability to introduce a new service increases with the intensity of ICT use.
Hypothesis 1b:	The probability to introduce a new process increases with the intensity of ICT use.
Hypothesis 1c:	The probability to introduce a new organisational model increases with the intensity of ICT use.
Hypothesis 1d:	The probability to introduce new marketing methods increases with the intensity of ICT use.

Box 1. **List of testable hypotheses by theme** *(cont.)*

2. Innovation trajectories

Hypothesis 2: Among all firms introducing a new product, the probability to introduce a product new-to-the-market (as opposed to new-to–the-firm) increases with the intensity of ICT use.

Hypothesis 3: Among all firms introducing a new product, the probability to introduce a new product developed in-house or in co-operation with other firms (as opposed to "developed by other firms") increases with the intensity of ICT use.

Hypothesis 4: Among all firms introducing a new process, the probability to introduce a new process developed in-house or in co-operation with other firms (as opposed to "developed by other firms") increases with the intensity of ICT use.

Hypothesis 5a: Among all innovative firms, the probability to innovate in organisation OR marketing increases with the intensity of ICT use.

Hypothesis 5b: Among all innovative firms, the probability to innovate in organisation AND marketing increases with the intensity of ICT use.

Hypothesis 5c: Among all innovative firms, the probability to innovate in organisation increases with the intensity of ICT use.

Hypothesis 5d: Among all innovative firms, the probability to innovate in marketing increases with the intensity of ICT use.

Hypothesis 6a: Among all innovative firms, the probability that product innovations are integrated to marketing innovations increases with the intensity of ICT use.

Hypothesis 6b: Among all innovative firms, the probability that process innovations are integrated to organisation innovations increases with the intensity of ICT use.

Hypothesis 6c: Among all innovative firms, the probability that product innovations were integrated to organisation OR marketing innovations increases with the intensity of ICT use.

Hypothesis 6d: Among all innovative firms, the probability that process innovations were integrated to organisation OR marketing innovations increases with the intensity of ICT use.

3. Co-operation in innovation

Hypothesis 7: Among all innovative firms, the probability to innovate in co-operation with other firms or institutions increases with the intensity of ICT use.

4. Research questions

The aim of this research project is to assess the effects of ICTs as an enabler of innovation.

ICT has the potential to increase innovation by speeding up the diffusion of information, favouring networking among firms, reducing geographic limitations, and increasing efficiency in communication.

These effects can be analysed by looking at whether the use of ICT in firms is associated with:

1. A higher probability to innovate;

2. Specific features of innovation; and

3. A higher probability to co-operate in innovation.

We adopted a simple approach, which is to test whether the expected effects of ICT use on innovation are supported by the data. Therefore, the research consists of a set of 19 testable hypotheses about the effects of ICT use on innovation, grouped under three themes (see Box 1).

5. The model

The above hypotheses have been tested through a series of "probit equations with endogenous regressors" (Wooldridge, 2002; pp. 472-478). The probability to introduce an innovation with specific features (*e.g.* product, marketing, new-to-the-market, *etc.*) is modelled as a function of:

- the intensity of ICT use;
- whether the firm carried out R&D;
- the firm's size (number of employees); and
- the educational attainments of its employees (as a proxy of skills).

Endogeneity in this context arises from the fact that innovative capability may depend not only on ICT, R&D, firm's size and skills, but also on other firms' characteristics which cannot be observed, *e.g.* the capability, specific to each firm, to combine these factors. Therefore, innovative firms are more likely to see the opportunities from ICT and to use it more. In these circumstances, the ICT variable would simply capture unobserved differences in the firms' capability to innovate, rather than the effects on ICT use on innovation.

In order to control for the potential endogeneity of the ICT variable, we used an Instrumental Variable (IV) approach. We tested a number of variables from the ICT Business survey which could be used as an IV, *i.e.* they are expected to be correlated to ICT use but not to innovation. The variable e-government turned out to be a valid instrument in all countries except the Netherlands and Switzerland, where we used the lagged ICT variable as an IV.

The variable e-commerce is computed from the answers to the following questions ("Eurostat model for a Community Survey on ICT Usage and e-Commerce in Enterprises 2006"):

B7*. Did your enterprise interact with public authorities in the following ways, during 2005?		
	Yes	No
a) For obtaining information	❒	❒
b) For obtaining forms, *e.g.* tax forms	❒	❒
c) For returning filled-in forms, *e.g.* provision of statistical information to public authorities	❒	❒
d) Submitted a proposal in an electronic tender system (e-procurement)	❒	❒

Firms are asked to answer all questions with yes or no. The value e-government is computed as 0, if the firm answers no to all questions, or 1, if the firm answers yes to at least one question. Firms with higher ICT use also use e-government more (except in the

Netherlands and in Switzerland) but there is no reason to expect e-government to reflect unobserved differences in the firms' capability to innovate.

The lagged value of the ICT use was used as an IV based on similar reasons: firms with a higher use of ICT in the past also use ICT more at present but past ICT use is not likely to be correlated to unobserved differences in the firms' capability to innovate at present.

In more formal terms, we started with the following model:

$$Inno_i^* = \beta_0 + \beta_1 \ln(size_i) + \beta_2 R\&D_i + \beta_3 skills_i + \Sigma_j \gamma_j D_{j,i} + u_i \quad (1)$$

$$ICT_i = \delta_0 + \delta_1 \ln(size_i) + \delta_2 R\&D_i + \delta_3 skills_i + \delta_4 IV_i + \nu_i \quad (2)$$

$$Inno_i = 1 \ \ if \ \ Inno_i^* > 0; Inno_i = 0 \ \ otherwise \quad (3)$$

$$D_{j,i} = 1 \ \ if \ \ ICT_i = j; D_{j,i} = 0 \ \ otherwise \quad (4)$$

where $i = 1, 2, \ldots, N$ indicates the firms; $j = 1, 2, \ldots 5$ the frequency of ICT use; *R&D* is equal to 1 if the firm carries out R&D, 0 otherwise; and (u_i, v_i) is assumed to have a zero mean, bivariate normal distribution and to be independent of all exogenous variables in (2).

If u_i and v_i are correlated, ICT is endogenous and the Probit estimates of all variables in (1) are biased. Under the assumption of joint normality of (u_i, v_i), we can write:

$$u_i = \theta v_i + e_i \quad (5)$$

where $e_i \sim N[0, Var(u_i) - Cov(u_i, v_i)]$.

Therefore, the above model can be rewritten as:

$$Inno_i^* = \beta_0 + \beta_1 \ln(size_i) + \beta_2 R\&D_i + \beta_3 skills_i + \Sigma_j \gamma_j D_{j,i} + \theta \hat{\nu}_i + e_i \quad (6)$$

where $\hat{\nu}_i$ are the OLS residuals[2] of equation (2).

Equation (6) was estimated through a "two-stage conditional maximum likelihood" (Rivers and Vuong, 1988) with firm or industry random effects. And the Average Partial Effects (APEs) computed as the average of the Partial Effects (PEs) across $\hat{\nu}_i$.

Three countries (the Netherlands, Norway and Sweden) estimated the model as a 2-period panel with firms' random effects and industry dummies; due to data limitations, the remaining six countries estimated a cross-section with industries' random effects.[3]

In general, panel estimation permits a better control for unobserved differences in the firms' capability to innovate, so that the estimated effects of ICT may be larger in cross-country regressions. However, our cross-section estimates do not seem systematically larger than the panel estimates.

The model can be interpreted as a simultaneous model, where the decision to innovate and to use ICTs is taken jointly. In this sense, the model does not predict that ICT use is the *cause* of innovation, rather that ICTs are an *enabler* of innovation: firms use ICTs as a tool or a "platform" for innovation.

6. Main findings

Tables 2 and 3 show the findings of our analysis.[4] The intensity of ICT use was measured as the number of web facilities (0 to 3) in Table 2 and as the number of automated IT links (0 to 5) in Table 3. Both ICT use variables provide similar results, although the estimates based on the number of automated IT links are less stable. Therefore, in what follow, we will focus on the results based on the number of web facilities.

6.1. Innovation capabilities

6.1.1. ICT use increases the probability to innovate

The number of web facilities increases the probability to innovate for the manufacturing firms in four countries out of eight. The increase is the highest in Spain and Italy, where firms with three web facilities are 81% and 66%, respectively, more likely to innovate than firms with no web facilities. In Canada and the United Kingdom the increase is 26% and 22%, respectively. Firms with two web facilities in Norway are 8% more likely to innovate, although the effect becomes non significant for a higher number of facilities.

The number of web facilities increases the probability to innovate for the service firms in five countries out of seven. The increase is the highest in Spain and Italy, where firms with three web facilities are over 60% more likely to innovate than firms with no web facilities. In Norway and the United Kingdom the increase is 27% and 26%, respectively. Firms with three web facilities in Switzerland are 7% more likely to innovate than firms with no web facilities.

6.1.2. ICT use increases the probability to introduce a new product both in manufacturing and services

The number of web facilities increases the probability to introduce a new product for the manufacturing firms in five countries out of eight. The increase is the highest in the Netherlands, where firms with three web facilities are 81% more likely to innovate in product than firms with no web facilities. The increase is 31% both for Canada and Italy. In the United Kingdom and Spain the increase is 23% and 11%, respectively. Firms with two web facilities in Norway are 14% more likely to introduce a new product, although the effect becomes non significant for a higher number of facilities.

The effect of ICT on the probability to introduce a new product in manufacturing seems limited to new goods. In fact, the effect on the probability to introduce a new service is lower or not significant.

The number of web facilities increases the probability to introduce a new product for the service firms in six countries out of seven. The increase is the highest in the United Kingdom and Italy, where firms with three web facilities are 32% and 21% more likely to innovate in product than firms with no web facilities. In Norway, the Netherlands, and Switzerland, the increase is 14%, 13 and 12%, respectively, while it is 8% in Spain.

The effect of ICT use on the probability to introduce a new product in services mainly occurs through new services. The only exception is the Netherlands, where the effect of web facilities is higher on new goods (32%) than on new services (14%).

6.1.3. ICT use has a significant effect on the probability to introduce a process innovation

A significant effect of web facilities on the probability to introduce a new production process in manufacturing was found only in Italy, the Netherlands and Switzerland. In these countries, firms with three web facilities are 35%, 12% and 7% more likely to innovate in process than firms with no web facilities.

As for services, a significant effect was found in Spain (37%), Italy (27%) and Norway (16%).

Table 2. **Increase in the probability to innovate associated with the intensity of ICT use (number of web facilities) – Manufacturing**

	Canada			Italy			Luxembourg			Netherlands			Norway			Spain			Switzerland			United Kingdom		
Number of web facilities	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Innovation capabilities																								
1. Any innovation (%)	13**	22***	26***	31***	50***	66***	71	94	87	61	95	98	5	8*	7	35**	68***	81***	n.a.	n.a.	n.a.	. .	14**	22***
1a. New product (%)	19***	29***	31***	19***	30***	31***	9	20	17	45***	70***	81***	3	14***	10	–3	6*	11***	n.a.	n.a.	n.a.	11*	15**	23***
1a1. New good (%)	16***	27***	34***	19***	26***	29***	. .	. .	. .	49***	69***	77***	2	9*	0	–5	4	9***	n.a.	n.a.	n.a.	. .	15**	22***
1a2. New service (%)	–43	–59	–52	4**	12**	9*	. .	. .	. .	5	4	5	1	3*	8***	–6	2	3	n.a.	n.a.	n.a.	7*	9*	8*
1b. New process (%)	–1	11	5	19***	26***	35***	–14	–13	–13	3	7	12***	–1	4	–4	28	44	54	n.a.	2	7*	. .	. .	. .
1c. New organisation (%)	5	10	24**	19***	31***	43***	10	40**	–1	7	13***	16***	2	6	1	3	8***	13***	n.a.	n.a.	n.a.	12*	13*	19***
1d. New marketing (%)	7	22***	29***	19***	23***	38***	7	23**	4	18***	26***	36***	7*	20***	18***	6	7***	16***	n.a.	n.a.	n.a.	. .	. .	18***
Innovation trajectories (%)																			n.a.	n.a.	n.a.			
2. New-to-the-market (%)	7	20*	12	3	11	0	26	24	–2	3	–3	2	3	5	4	12	–5	–5	n.a.	5	10*	. .	. .	. .
3. Prod. in-house/co-op. (%)	n.a.	n.a.	n.a.	2	2	4	. .	. .	. .	65	95	98	–1	–2	–2	9	–4	5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
4. Proc. in-house/co-op. (%)	n.a.	n.a.	n.a.	0	1	3	. .	. .	. .	–8	–3	–8	4	–3	–1	–14	–2	–1	n.a.	n.a.	n.a.	. .	. .	. .
5a. Org. or marketing (%)	–3	0	14	1	3	11***	. .	. .	. .	4	12**	16**	5	13***	11*	6	1	7**	n.a.	n.a.	n.a.	. .	. .	. .
5b. Org. and marketing (%)	4	17**	23**	9***	9***	20***	5	31*	6	13**	16**	28**	5	15***	7	3	5	13***	n.a.	n.a.	n.a.	. .	. .	. .
5c. Organisation (%)	–4	–4	10	–1	3	7*	–1	18	–3	–1	3	10**	1	6	–2	0	–2	1	n.a.	n.a.	n.a.	. .	. .	. .
5d. Marketing (%)	6	22**	27**	11***	10***	23***	6	21	2	17***	26***	37***	8*	23***	20***	8	7**	17***	n.a.	n.a.	n.a.	. .	. .	15*
6a. Prod. and marketing (%)	13*	27***	27**	5*	9**	16***	0	1*	0	8*	14***	18***	8	20***	14*	5	–1	7*	n.a.	n.a.	n.a.	. .	. .	23**
6b. Proc. and org. (%)	–11	–11	–2	6*	14***	15***	–20	0	–10	2	5	7	–41	–57	–73	12	3	5*	n.a.	n.a.	n.a.	. .	. .	. .
6c. Prod. and mktg/org. (%)	10	15	29**	3	8***	11***	. .	. .	. .	9	14**	17**	3	15***	8	17	1	8	n.a.	n.a.	n.a.	. .	14*	19**
6d. Proc. and mktg/org. (%)	–11	–5	–2	6***	10***	15***	–22	–7	–20	4	6	12	0	12**	1	7	3	6	n.a.	n.a.	n.a.	30**	40**	39**
Co-operation in innovation																								
7. Co-op. (%)	n.a.	n.a.	n.a.	6***	3*	–1	. .	. .	. .	2	6	1	0	1	–3	–2	–6	–3	n.a.	n.a.	n.a.	. .	16*	14*
Data	Cross-section			Cross-section			Cross-section			Panel			Panel			Cross-section			Panel			Cross-section		
Estimation	Random Effects			Random Effects			Random Effects			Random Effects			Random Effects			Random Effects			Random Effects			Random Effects		
No. of observations	488			2 479			128			675			1 697			2 569			1 888			632		

* Significant at 10%.
** Significant at 5%
*** Significant at 1%.
. .: Non significant.
n.a.: Not available.

Table 2. **Increase in the probability to innovate associated to the intensity of ICT use (number of web facilities) – Services** *(cont.)*

	Italy			Luxembourg			Netherlands			Norway			Spain			Switzerland			United Kingdom		
Number of web facilities	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Innovation capabilities																					
1. Any innovation (%)	42***	60***	61***	–6	–4	5	1	3	3	14***	23***	27***	37***	47***	60***	n.a.	n.a.	7***	17***	18***	26***
1a. New product (%)	17***	22***	21***	3	10	24	4	14**	13**	4	10**	14**	6	3	8***	n.a.	n.a.	12**	21***	23**	32***
1a1. New good (%)	10***	11***	10***	2	8	9	29***	35***	32***	3	6*	0	10	0	3	n.a.	n.a.	10***	. .	. .	. .
1a2. New service (%)	13***	18***	18***	3	16	24*	0	10*	14**	2	6*	14***	3	3	8***	n.a.	n.a.	n.a.	21**	23**	32***
1b. New process (%)	21***	22**	27**	–13	–8	–9	–7	–1	–2	7	8**	16***	30	30***	37***	n.a.	n.a.	n.a.	. .	. .	. .
1c. New organisation (%)	32***	49***	46***	–6	–20	–7	0	10	5	5	9*	19***	10	34***	42***	n.a.	n.a.	n.a.	18***	16***	23***
1d. New marketing (%)	7***	10***	14***	–4	–4	5	12**	22***	38***	7	16***	22***	10	4***	10***	n.a.	n.a.	n.a.	12***	17***	18***
Innovation trajectories																					
2. New-to-the-market (%)	–3	5	14	17	10	10	1	16**	–2	–10	–19	1	71	7	13	n.a.	n.a.	n.a.	. .	. .	. .
3. Prod. in-house/co-op. (%)	5	–8	14	–13	–17	–8	6	9*	1	2	5	8	–18	7	1	n.a.	n.a.	n.a.	19**	19**	18*
4. Proc. in-house/co-op. (%)	4	–6	9	. .	. .	. .	–11	0	3	1	–3	12	15	4	8	n.a.	n.a.	n.a.	0	0	0
5a. Org. or marketing (%)	–1	5*	1	0	–23	–10	5	14**	12*	2	6	8	–38	3	4	n.a.	n.a.	n.a.	12**	. .	. .
5b. Org. and marketing (%)	5	9**	15***	–3	–6	5	–8	–1	4	–7	–2	12	11	–3	5	n.a.	n.a.	n.a.	34**	44**	43**
5c. Organisation (%)	–4	3	–3	1	–29	–15	–5	3	–3	–7	–7	4	–34	1	2	n.a.	n.a.	n.a.	. .	. .	. .
5d. Marketing (%)	7**	10**	18***	–3	–2	8	12**	22***	40***	1	10	17	7	0	7	n.a.	n.a.	n.a.	. .	19*	16*
6a. Prod. and mktg (%)	8	6	5	–37	–57	–60	3	8	25***	–1	7	9	18	–5	–3	n.a.	n.a.	n.a.	27**	27**	32**
6b. Proc. and org. (%)	4	3	5	–8	–9	–11	12*	11*	17**	–3	–10	3	–15	4	6	n.a.	n.a.	n.a.	. .	. .	. .
6c. Prod. and mktg/org. (%)	6**	4*	6**	0	–2	8	–4	9	8	3	11	13	21	–1	2	n.a.	n.a.	n.a.	29***	27***	38***
6d. Proc. and mktg/org. (%)	5**	5**	4	–4	–8	–4	13*	14**	22***	3	2	14	–15	4	7	n.a.	n.a.	n.a.	. .	. .	. .
Co-operation in innovation																					
7. Co-op. (%)	3	4*	3	–2	–4	0	16***	17***	22***	–15	–15	–17	–1	3	8	n.a.	n.a.	n.a.	. .	. .	. .
Data	Cross-section			Cross-section			Panel			Panel			Cross-section			Panel			Cross-section		
Estimation	Random Effects			Random Effects			Random Effects			Random Effects			Random Effects			Random Effects			Random Effects		
No. of observations	1 912			210			600			1 273			2 201			1 469			1 069		

* Significant at 10%.
** Significant at 5%
*** Significant at 1%.
. .: Non significant.
n.a.: Not available.

Table 3. **Increase in the probability to innovate associated to the intensity of ICT use (number of IT links) – Manufacturing**

	Canada		Italy					Luxembourg					Netherlands					Norway					Spain					United Kingdom				
Number of IT links	1-2	3-5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Innovation capabilities																																
1. Any innovation (%)	25	14	. .	. .	. .	. .	. .	–1	26*	28*	32	27	–8	–3	1	–3	1	2	–1	8***	2	0	58	76	83	86	90	. .	. .	7**	. .	. .
1a. New product (%)	13	–6	17***	25***	26***	33***	45***	–1	–4	18	–25	14	–12	1	6***	1	4	1	4	6*	–3	1	9***	12***	13***	12***	12***	13***	20***	40***	44***	47***
1a1. New good (%)	14	–2	16***	22***	25***	30***	41***	. .	. .	. .	. .	. .	–19	–2	7	4	6	0	4	8**	2	5	6*	9***	11***	13***	14***	. .	. .	13***	11**	7*
1a2. New service (%)	1	0	7	9**	6	10	21*	. .	. .	. .	. .	. .	2	5	0	2	–1	0	0	–1	–4	–2	5**	3	4*	6*	2	. .	. .	. .	. .	. .
1b. New process (%)	13	7	13***	26***	28***	33***	47***	–8	9	–10	–1	1	–8	–2	–1	0	2	5	5	–1	–4	–1	5	9***	16***	19***	17***	. .	. .	7*	12**	11***
1c. New organisation (%)	27***	31***	. .	. .	. .	. .	. .	0	1	43**	–8	13	–5	–8	0	5	10**	–3	1	5*	0	5	14***	10***	12***	13***	13***	. .	. .	. .	. .	. .
1d. New marketing (%)	10	3	16***	25***	24***	33***	36***	–4	6	9	7	0	–6	–8	–5	8**	9**	–5	6	7**	12**	11**	7***	9***	11***	11***	10***	. .	. .	. .	. .	. .
Innovation trajectories																																
2. New-to-the-mkt (%)	12	–6	3	14**	1	13**	12**	–14	–28	–9	10	–41	0	1	0	5	2	11	–1	1	1	17**	–2	–1	0	2	2	. .	. .	. .	. .	. .
3. Prod. in-house/co-op. (%)	n.a.	n.a.	3	0	3	1	1	. .	. .	. .	. .	. .	1	–2	1	5	2	4	4	1	4	4	5	9	6	7	7*	. .	. .	. .	. .	. .
4. Proc. in-house/co-op. (%)	n.a.	n.a.	1	1	2	2	0	. .	. .	. .	. .	. .	–5	–1	8***	15***	6	1	–7	–2	–5	0	2	4	5*	4	6*	. .	. .	. .	. .	. .
5a. Org. or mrktg (%)	7	20**	–3	2	1	3	0	. .	. .	. .	. .	. .	–5	–10	–2	11**	11**	–5	5	6**	10**	12**	8**	5**	5***	6***	5***	. .	. .	. .	. .	. .
5b. Org. and mrktg (%)	11	6	6	2	2	7	2	1	8	22	14	0	–1	–4	–4	6**	7***	–9	4	0	2	7	7	7	11	13	8	. .	. .	. .	. .	. .
5c. Org. (%)	14	26***	–7	0	2	0	–2	–5	–32	13	–24	–8	–1	–7	–1	7	10**	–6	1	2	–1	7	7	3	5	6	4	. .	. .	. .	. .	. .
5d. Mrktg (%)	4	1	9*	5	1	10*	4	–6	–5	0	0	–9	–4	–7	–6	9**	9**	–9	9*	4	14**	14**	7*	9***	11***	12***	9***	. .	. .	. .	. .	. .
6a. Prod. and mktg (%)	–9	–6	10*	3	3	8	4	0	0	0	1	0	–1	–6	–7	7	9*	–11	3	–1	1	8	8**	7*	10***	12***	5	. .	. .	. .	. .	. .
6b. Proc. and org. (%)	–4	7	–1	2	2	11**	8**	–41	–29	–22	–33	–25	–2	–1	–3	7	7	–4	5	–1	–5	14	12***	11***	19***	21***	14***	15**	. .	24***	31***	35***
6c. Prod. and mktg/org.	0	4	7*	1	3	6*	3	. .	. .	. .	. .	. .	–2	–13	1	5	10*	–7	6	1	4	8	8*	7*	10**	11**	7*	. .	–9*	. .	. .	. .
6d. Proc. and mktg/org.	–7	4	5	0	–1	9**	5*	–46	–71	–65	–81	–78	–2	–1	–4	9	7	–4	8	0	–7	5	11***	10***	19***	20***	12***	16**	. .	26***	33***	39***
Co-operation in innovation																																
7. Co-op. (%)	n.a.	n.a.	–2	–1	–2	–2	2	. .	. .	. .	. .	. .	–8	6	4	13***	20***	12*	4	6*	4	9	5**	9	6***	7***	7***	. .	13**	29***	36***	45***
Data	Cross-section		Panel					Cross-section					Panel					Panel					Cross-section					Panel				
Estimation	Random Effects		Random Effects					Random effects					Random Effects					Random Effects					Random Effects					Random Effects				
No. of observations	488		2 479					134					278					1 697					1 993					1 446				

* Significant at 10%.
** Significant at 5%
*** Significant at 1%.
. .: Non significant.
n.a.: Not available.

Table 3. **Increase in the probability to innovate associated to the intensity of ICT use (number of IT links) – Services** *(cont.)*

	Italy					Luxembourg					Netherlands					Norway					Spain					United Kingdom				
Number of IT links	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Innovation capabilities																														
1. Any innovation (%)	28***	62***	56***	64***	73***	3	8*	7	6	6	0	1	0	–4	1	15**	13**	11**	14**	22***	15***	23***	21***	18***	23***	. .	. .	6*	. .	. .
1a. New product (%)	7***	25***	21***	23***	32***	36**	45**	40**	25*	42**	2	3	3	–5	1	11	7	17***	10**	18***	2	2	7**	1	6**	10***	11***	18***	22***	21**
1a1. New good (%)	6***	17***	9**	12***	20***	9	8	2	6	6	4	18***	39***	17***	26***	3	5**	13***	5	8**	0	1	5**	2	6***	4*	4*	6***	7***	7***
1a2. New service (%)	4	17***	17***	20***	23***	6	13	5	–7	10	12***	5	–2	0	–1	6	–1	2	8**	8**	3	2	7***	3	6***	. .	. .	. .	. .	. .
1b. New process (%)	11***	28***	25***	37***	36***	–6	–2	–3	17	23	–9	5	–6	2	–5	3	4	8**	12**	24***	12***	19***	20***	18***	21***	. .	. .	. .	–6	. .
1c. New organisation (%)	24***	43***	47***	52***	59***	2	6	8	8	–7	–5	–1	–3	2	–9	11**	4	8**	7	15***	10***	14***	7**	13***	19***	. .	. .	. .	. .	. .
1d: New marketing (%)	0***	10***	7**	7**	18***	3	12*	17**	6	2	7	12***	21***	19***	19***	2	5	10***	17***	20***	–1	4*	2	5*	11***	11**	18**	24**	29**	32**
Innovation capabilities																														
2. New-to-the-mkt (%)	1	9	–12	–12	0	18	9	2	10	12	–7	–2	–1	–4	1	13	17	8	15	1	–1	14*	13*	2	22***	. .	. .	. .	. .	. .
3. Prod. in-house/co-op. (%)	–7	10	15	0	7	. .	. .	. .	. .	. .	5	–5	6	1	0	1	–2	–6	–8	–8	5	–14	–2	–4	2	. .	. .	. .	. .	. .
4. Proc. in-house/co-op. (%)	4	3	12*	10	5	. .	. .	. .	. .	. .	–2	–2	2	1	9	–4	–12	3	–1	–5	1	–1	9	13**	1	. .	. .	. .	. .	. .
5a. Org. or mrktg (%)	1	–4	0	–1	0	1	–10	5	–2	–26	–6	–2	1	5	–6	–4	–2	1	5	3	–1	–1	–11	–2	4*	. .	. .	. .	. .	. .
5b. Org. and mrktg (%)	–1	3	15***	11**	21***	–3	13	17	–3	2	3	8*	12**	12*	11*	0	–6	11**	8	14**	–9	–5	–6	4	8	. .	. .	. .	. .	. .
5c. Org. (%)	2	–7	6	3	1	–11	–14	–7	–15	–33	–6	–1	–3	5	–10	5	–5	4	–3	3	0	–3	–12	0	4	. .	. .	. .	. .	. .
5d: Mrktg (%)	–2	4	8	5	17***	3	15	24*	5	3	6	11**	21***	20***	18***	–9	–2	7	16**	13*	–10	–4	–7	0	7	. .	25*	31*	41*	45*
6a. Prod. and mktg (%)	–12	2	–1	6	4	–11	14	10	–27	–2	–4	–5	3	7	6	–14	–8	0	4	19	–2	–5	–3	–2	7	. .	. .	. .	. .	–8*
6b. Proc. and org. (%)	3	3	9*	15***	11**	–5	2	–5	6	4	–8	0	–8	8	–2	4	1	12**	9	26***	4	9	–1	11**	14***	. .	. .	. .	. .	. .
6c. Prod. and mktg/org. (%)	–5	1	1	4	7**	9	2	6	–4	–7	–3	4	4	1	–3	–1	–1	20***	11	17**	6	–5	–1	–4	6	15**	21**	27**	29**	31**
6d. Proc. and mktg/org. (%)	0	3	10***	10***	13***	–6	7	–2	4	10	–6	1	–7	8	–2	–6	–1	8	8	25***	4	10**	3	12**	18***	. .	. .	. .	–8**	. .
Co-operation in innovation																														
7. Co-op. (%)	2	–2	–2	3	1	3	3	9	8	5	1	4	3	–2	7	1	1	5	–2	1	4	12***	12***	16***	19***	. .	. .	. .	. .	. .
Data	Cross-section					Cross-section					Panel					Panel					Cross-section					Panel				
Estimation	Random Effects					Random Effects					Random Effects					Random Effects					Random Effects					Random Effects				
No. of observations	1 912					210					235					1 273					1 336					2 630				

* Significant at 10%.
** Significant at 5%
*** Significant at 1%.
. .: Non significant.
n.a.: Not available.

6.1.4. ICT use increases the probability to introduce a new organisation

The number of web facilities increases the probability to innovate in organisation for the manufacturing firms in five countries out of eight. The increase is the highest in Italy, where firms with three web facilities are 43% more likely to innovate in organisation than firms with no web facilities. In Canada, the United Kingdom, the Netherlands and Spain the increase is 24%, 19%, 16% and 13%, respectively. Firms with two web facilities in Luxembourg are 40% more likely to innovate, although the effect becomes non significant for a higher number of facilities.

These effects are confirmed for services in four countries out of seven. The increase is the highest in Spain and Italy, where firms with three web facilities are, respectively, 46% and 43% more likely to introduce a new organisation than firms with no web facilities. In Norway and the United Kingdom the increase is 19% and 23%, respectively.

6.1.5. ICT use increases the probability to innovate in marketing

The number of web facilities increases the probability to innovate in marketing for the manufacturing firms in six countries out of eight. The increase is the highest in Italy and the Netherlands, where firms with three web facilities are 38% and 36%, respectively, more likely to innovate than firms with no web facilities. The increase is 29% in Canada, 18% in Norway and the United Kingdom, and 16% in Spain. Firms with two web facilities in Luxembourg are 23% more likely to innovate in marketing, although the effect becomes non significant for a higher number of web facilities.

The number of web facilities increases the probability to innovate in marketing for the service firms in five countries out of seven. The increase is the highest in the Netherlands, where firms with three web facilities are 38% more likely to innovate than firms with no web facilities. In the remaining countries this effect seems weaker than in manufacturing. The increase in the probability to innovate in marketing is 22% in Norway, 18% in the United Kingdom, 14% in Italy and 10% in Spain.

6.2. Trajectories in innovation

6.2.1. ICT use does not increase the probability to introduce a product new-to-the-market

The introduction of a new product by a firm may result from the adoption of an existing product, *i.e.* new-to-the-firm, or by the invention of a truly new product, *i.e.* new-to-the-market. If ICT use increased the invention capabilities of a firm, one may expect new products by ICT-intensive users to be new-to-the-market more often than new-to-the-firm.

Against this expectation, we found that ICT use does not increase the probability to introduce a product new-to-the-market – as opposed to new-to-the-firm. Manufacturing firms in Switzerland are the only ones to show a higher probability (10%) although the statistical significance of this result is weak (10%).

6.2.2. ICT use does not increase the probability to develop a new product or process in-house

The introduction of a new product or process by a firm may result from the adoption of an existing product/process developed by another firm or by the invention of a new product/process developed in-house. If ICT use increased the invention capabilities of a firm, one may expect new products/process by ICT intensive users to be mostly developed in-house (or in co-operation with other firms).

In general, we found little evidence that ICT use increases the probability to introduce a new product or a new process developed in-house. Service firms in the United Kingdom are the only ones to show a higher probability (up to 19%) to develop a new product in-house or in co-operation with other firms.

6.2.3. Among all innovative firms, ICT-intensive users are more likely to innovate in organisation or marketing

The number of web facilities increases the probability to innovate in marketing for the innovative manufacturing firms in six countries out of seven. The increase is the highest in the Netherlands, where innovative firms with three web facilities are 37% more likely to innovate in marketing than innovative firms with no web facilities. The increase is over 20% in Canada, Italy and Norway and it is 17% and 15% in Spain and the United Kingdom, respectively. In this latter country, the probability to innovate both in process and marketing/organisation increases up to 40%.

In the service industries, the intensity of ICT use increases the probability to innovate in marketing among innovative firms in the Netherlands (40%) and Italy (18%). In the United Kingdom, ICT use increases the probability to innovate in process and marketing/organisation (38%) as well as in product and marketing/organisation (32%).

6.3. Co-operation in innovation

6.3.1. ICT use does not increase probability to co-operate in innovation

In general, we found little evidence for the hypothesis that ICT intensive users are more likely to co-operate in innovation with other firms or institutions. The only firms where ICT use is associated with a higher probability to co-operate in innovation are manufacturing firms in the United Kingdom (16%) and services firms in the Netherlands (22%).

6.4. Cross-country comparisons

The above results point to significant effects of ICT use on the probability to innovate in a majority of countries. However, the size of these effects varies considerably among them. Although the information available does not permit a full explanation of the estimated differences, it is worth examining some potential causes.

First, differences in the sample size may lead to different precision of the estimates. Although the estimates tend to be large and significant in Italy and Spain, the largest samples, and small and non significant in Luxembourg, the smallest sample, countries with a relative small sample (Canada, Netherlands and the United Kingdom) tend to show significant estimates whereas Switzerland show few significant estimates despite its large sample.

Second, panel estimation permits a better control for unobserved differences in the firms' capability to innovate, so that the estimated effects of ICT may be larger in cross-country regressions. However, this does not seem the case. The panel estimates for the Netherlands are similar or even bigger than the cross-country estimates for Italy and Spain. Panel estimates for services in Norway are in line with cross-country estimates for services in the United Kingdom.

Third, different estimates may be due to the use of different instruments. Against this explanation, the Netherlands and Switzerland show very different estimates despite the

use of the same IV (lagged value of ICT use) and the same panel estimation; whereas Norway and the Netherlands show similar panel estimates in services although they use different IV.

Finally, the estimated effects of ICT are consistently larger in three countries: Italy, the Netherlands and Spain. In Italy and Spain, the diffusion and use of ICT by firms is lower than in the other countries considered in this study. This suggests that the effects of ICT on innovation are stronger when ICT adoption is low, a result consistent with the order-effect of the diffusion theory: the benefits from the use of a new technology are higher for earlier adopters and decrease as the number of adopters increases.

This interpretation, however, is not plausible for the Netherlands, where the rate of diffusion of ICT among business is among the highest in OECD countries.

Overall, cross-country differences in the estimated effects of ICT on innovation seem to be mainly due to the characteristics of the data rather than to the sample size, the estimation approach or some country-specific features. This interpretation appears consistent with the characteristics of innovation survey data highlighted in the econometric literature (Mairesse and Mohnen, 2010).

7. Conclusions and suggestions for further research

This study has tried to assess the effects of information and communications technologies (ICTs) as an enabler of innovation in eight OECD countries. Our findings support the hypothesis that ICTs act as an enabler of innovation, in particular for product and marketing innovation. Unlike previous studies, our results show that these effects are large both in manufacturing and services.

However, we did not find any evidence that ICT use increases the capability of a firm to co-operate with other firms/institutions nor that ICT intensive firms have higher capacity to develop innovation in-house or to introduce more "innovative" (new-to-the-market) products. These results suggest that ICTs enable firms to adopt innovation but they do not increase their "inventive" capabilities, *i.e.* the capability to develop new products and processes.

In interpreting these results, one should bear in mind that they are based on some "imperfect" measure of ICT use by firms. As discussed above, firms with the same automatic IT links or web facilities may use them differently and our indicators would not capture these differences. In addition, these indicators seem biased towards the use of ICTs for e-commerce and e-business but they may be a poorer proxy for other ICT-enabled activities relevant for innovation, *e.g.* communication.

One development of the present study, therefore, would be to test the above results against some alternative indicator of ICT use. For instance, the analysis could be repeated using ICT investments for the few countries where data are available at the firm level.

If the results were confirmed, another development of the present study would be to have researchers from additional countries join the network and apply the research model developed for this study.

Another direction for further research would be to link the present results to an analysis of productivity at the firm level. Do ICT-enabled innovations have a different impact on productivity as compared with other types of innovation? Do they act through different channels? This line of research requires linking ICT and innovation micro data to

business registers or business surveys and introducing ICT variables into a broader productivity model.

Most important, further research should try to fill the gap between econometric outputs and policy demand. Policy-makers can benefit from cross-country comparisons to the extent that the results can be related to differences in economic and institutional settings. Unfortunately, micro-data analysis is still a long way from this objective, particularly in the field of ICT and innovation. Co-ordinated research projects, like the ones carried out by the OECD and Eurostat, can significantly improve the policy relevance of this work.

Notes

1. Sylvain Ouellet (Canada), Valeria Mastrostefano and Alessandra Nurra (Italy), Leila Ben-Aoun and Anne Dubrocard (Luxembourg), Thomas Kooten and George van Leeuwen (Netherlands), Marina Rybalka (Norway), Olga Ureña Fernandez and Maria Martinez (Spain), Hans-Olof Hagén (Sweden), Martin Woerter (Switzerland), Peter Stam and Mark Franklyn (United Kingdom). The project benefitted from comments by Andrea Panizza and Marc Bogdanowicz (EC-IPTS, Seville).
2. As ICT is a discrete variable, the OLS estimates of $\hat{\nu}_i$ are not consistent. Nonetheless, they lead to consistent estimates of equation (6) because they are orthogonal to all exogenous variables – see, for instance, Heckmann (1978).
3. We did not test for fixed effects because this would lead to inconsistent estimates in the context of the "unobserved effects probit model" used in this study (Wooldridge, 2002, p. 484). This situation is known as the "incidental parameters problem".
4. The results were not significant for Sweden. This is probably due to the combination of two factors: a smaller number of observations and a lower variability in the ICT indicators due to the higher sophistication of ICT use by Swedish firms. An earlier study, based on the same dataset but using a different model, found that ICT use increases both the probability to innovate and the innovation activities among innovators ("ICT use, Broadband and Productivity in Sweden") *www.scb.se/statistik/_publikationer/OV9999_2008A01_BR_X76BR0802.pdf*.

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