Impact of R&D and ICT on Innovation and Productivity. Empirical evidence from micro data

Thuc Uyen Nguyen Thi* & Martin Ludivine†
CEPS/INSTEAD

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Abstract

This paper raises the question of the relationship between innovation and productivity conditional to ICT use and R&D activities during the innovation process. Concretely, we wonder whether R&D activities and ICT use considered as innovation inputs play a role in determining the probability of introducing technological and non technological innovations and whether these innovation outputs conditional to ICT use and R&D lead to a higher level of labour productivity. In this adaptation of CDM model extended with ICT use, we consider a four equations model that relates labour productivity to innovation outputs, innovation outputs to R&D and ICT use, and R&D and ICT use to their determinants. Our robust three-step estimations underline the benefits of taking into account the joint endogeneity of the key variables of the whole system. Unlike the previous empirical literature, we introduce in the model a large set of indicators of ICT use to capture the degree of variety and sophistication of ICT and distinguish two types of R&D activities, internal and external R&D instead of constituting aggregated measures of ICT use and R&D. We observe that while confirming the acknowledged 'innovation-enabler' role of some ICT, the results point out the fact that not all increases in ICT investments translate into equivalent increase in firm capacity to introduce new products/processes or in an improvement of innovative performance. In addition, the productivity effect of product innovation appears only at the moment of its commercial success, measured as the turnover percentage of sales generated from new or improved products. Furthermore, estimation results confirm the acknowledged belief that new or improved organizational arrangements, conditional to ICT platforms, lead to a subsequent improvement of product quality, timeliness, reduce waste, transactions and coordination costs, which could, in turn, result in an improvement of the labour productivity.

Key words: Innovation; Productivity; R&D; ICT; Organizational innovation; CIS

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*CEPS/INSTEAD, BP 48, L-4501 Differdange, Luxembourg. Tel.: +352. 58.58.55.632, e-mail: thithu-cuyen.nguyen@ceps.lu

† *Corresponding author.* CEPS/INSTEAD, BP 48, L-4501 Differdange, Luxembourg and Center for Research in Economics and Management (CREM-UMR CNRS 6211) - Department of Economics, 7, place Hoche, 35065 Rennes, France. Tel.: +352 58 58 55 631 - Fax: +352 58 55 60 , e-mail: ludivine.martin@ceps.lu

1. Introduction

Today, firms face a changing environment characterized by the rapid advance of globalization, the emergence of new competitors and diversification of demand. In this context, firms' innovative capabilities depend not only on firms' internal competencies, e.g. Research and Development activities (R&D), but also on their capacity to develop organizational strategy for managing their innovation process. In this context, the Information and Communication Technologies (ICT) use could be "a part of a larger system of technological and organizational changes that increased productivity over time" (Brynjolfsson and Hitt, 1997). Actually, the effects of R&D and ICT use on innovation and productivity constitute two separate well-established streams of literature.

Concerning the effects of R&D, several innovation studies have taken it as a starting point for analysis of innovative activities across firms (Mairesse and Sassenou, 1991; Griliches, 1995, 2000; Mairesse and Mohnen, 2001, 2005). R&D is widely recognized to be the technological advance driver and levels of growth of R&D expenditures are considered as reliable indicators of innovative capacity.

The knowledge production processes through R&D investment are widely assumed to have two different types of effects: one direct and one indirect. As for the direct effect, R&D "stimulates" the development of new products or processes, and in many cases, the creation of new markets (Griffith, Redding, and Van Reenen, 2004). Although firms develop traditionally in-house R&D, external relations with other firms or public institutions, through alliances, partnerships, outsourcing or sub-contracting, are becoming an credible alternative in relation with firm R&D activities. Hence, because of the tacit and non transferable character of knowledge and of the evolutionary and continual character of the learning process, innovative firms should concentrate on their specific capabilities while involving in cooperative arrangements in order to develop new skills and extensions of the firm's know-how to new applications. Firms should moreover be encouraged to engage in R&D cooperation in order to have access to partners' complementary or synergistic skills and capitalize "incoming spillovers" (Kogut and Zander, 1993; Cassiman and Veugelers, 2006), to reduce the duplication of R&D efforts as well as risks and costs associated to innovation projects (Jacquemin, 1988; Sakakibara, 1997) and to benefit from economies of scale or scope (Kogut, 1988). As a consequence, R&D is widely accepted to be essential to the evolution of firms' performance (Griliches, 1986; Hall and Mairesse, 1995).

As for the indirect effect, intramural and extramural R&D undertaken has an important role in promoting 'absorptive capacity' (the "second face of R&D") which is identified by the literature as one of sources of productivity growth (Grossman and Helpman, 1991; Romer, 1990; Griffith, Redding, and Van Reenen, 2004). When investing in R&D, firms are involved in a process of learning and adaption which should allow to acquire the "ability to recognize the value of new information, assimilate it, and apply it to commercial ends" (Cohen and

Levinthal, 1990). If a firm masters its absorptive capacity, it can take advantage, not only of its own innovative efforts, but also of the fruits of others' R&D investments which could result in substantial improvements of firm innovativeness. Several empirical studies find evidence in support of the importance of R&D on productivity through its effect on facilitating the absorption and transfer of new technologies (Geroski, 1995; Eaton, Gutierrez, and Kortum, 1998; Griffith, Redding, and Van Reenen, 2004; Parisi, Schiantarelli, and Sembenelli, 2006).

An abundant literature using individual firm data has focused on the direct and indirect role of R&D on innovation and productivity across the process of innovation (Lööf and Heshmati, 2006; Janz, Lööf, and Peters, 2004; Parisi, Schiantarelli, and Sembenelli, 2006). These empirical studies continue particularly the methodology line started by Crépon, Duguet, and Mairesse (1998) who first used a structural model including the allocation of resources to R&D activities, the innovation output and the productivity of firms which constitute the three stages of the whole process of innovation. This model (henceforth CDM model) points to the concept of "knowledge production function" (Griliches, 1986) recognizing that knowledge created through R&D capital stock is an important production factor of firm innovation output, and thus assumed to determine the level of productivity indirectly via its impact on innovation output.

As for the second stream of literature, the importance of ICT in promoting innovation and productivity is an issue that has attracted particular attention in recent innovation studies. Theoretical studies on the economic role of ICT are in general presented from two arguments: strategic management and cost reduction. The ICT use could change the optimal structure of the organization by enabling complementary organizational investments such as business processes and work practices and thus allow firms to be flexible and adaptive (Bresnahan, Brynjolfsson, and Hitt, 2002). According to these studies, ICT use may allow firm to access to complementary or new competencies developed elsewhere while concentrate in developing their specific internal ones, to roll out (new) products and to manage knowledge flows within and between firms (Brynjolfsson and Hitt, 2000; Kogut and Zander, 1993; Nelson and Winter, 1982). Implementing these investments could, in turn, result in substantial improvements in productivity by reducing costs and in improvements in organizational flexibility and intangible aspects of existing products like convenience, timeliness, quality and variety (Brynjolfsson and Hitt, 1997).

Numerous studies have also investigated the complementarity between organizational innovation and ICT by highlighting the importance of technological change as a driver of organizational changes within the firm (Henderson and Clark, 1990; Danneels, 2002). These studies have focused on the fact that ICT usually conduces to new methods or ways of organizing firms. Firms introducing ICT would be constrained to reorganize their production, workforce, sale and distribution systems. Another research line points out the inverse relationship by stressing the role of organizational innovation in enhancing flexibility, creativity - that in turn facilitates the development of ICT use. Using a sample of firms in the fast-moving consumer goods industry in Germany, Lokshin, van Gils, and Bauer (2008) studied the effect of organizational skills on firms' innovative performance, showing that firms implementing a combination of customer, organizational and technological skills tend to introduce more innovation.

It is surprising to note that few empirical works on the subject of the relation between innovation efforts and productivity using the methodology line started by Crépon et al. (1998) consider R&D and ICT use simultaneously in a same framework to estimate their effects on innovation and productivity. van Leeuwen and Farooqui (2008) incorporate in a CDM model the broadband connectivity and E-commerce as potentially important ICT drivers of productivity that can be channeled via innovation. They find evidence of the importance of ICT use for explaining differences in innovation success and the importance of ICT use on productivity through their effect on innovation output. Recently, Polder et al. (2009) also use the CDM model extended with ICT use considered as an additional innovation input besides R&D. This work is one of the first studies on the relationship between innovation and productivity, combining elements from both insights from the literature on R&D driven technological innovation and that on non-technological innovation complemented by ICT. Based on a data set issue from the merging of different surveys (Community Innovation Survey, Business ICT, Investment Statistics and Production Statistics), they find that ICT is most important for innovation success in the services sectors. ICT investments, the use of broadband and e-commerce, positively affect all product, process and organizational innovations in this sector. In addition, they find that organizational innovation is the only innovation type that leads to higher level of productivity.

Although these recent studies has substantially improved our understanding of the role of ICT use on innovation and productivity, the absence of appropriate data, being the barrier to the empirical study of this phenomenon, should explain the few empirical works on the subject. This is reflected in the development of the statistical systems where are traditionally separately undertaken the R&D and Innovation surveys and ICT surveys which focus on how firms use their ICT capital stocks. We are able to overcome such a difficulty thanks to two large and nationally representative datasets on R&D and Innovation on one hand and on ICT use on other hand.

In line with van Leeuwen and Farooqui (2008) who recommends to go further in the comprehension of firm performance, especially of the relative importance of ICT use and R&D driven innovation, the purpose of this paper is to investigate both the impact of R&D and ICT use on innovation firstly and the impact of innovation on firms' labour productivity secondly. In order to capture the direct and indirect effects of ICT use and R&D efforts on labour productivity, we use a variant of the structural modelling approach of the CDM model, extended with ICT use. More precisely, we perform a three-step analysis. First, we assess the determinants of innovation input (R&D and ICT use). Second, we investigate the impact of R&D intensity and ICT use as innovation inputs on innovation outputs. Third, we estimate the labour productivity with the introduction of the predicted innovation outputs issue from the second-step regression.

The main originality of this paper lies in its investigation of ICT use and R&D as innovation inputs in a same framework. In particular, we make use of a larger set of variables on ICT use than those used in the related literature such as ICT capital stock in constant prices (van Leeuwen and Farooqui, 2008) or ICT intensity measured by the log of ICT investment per employee (Polder et al., 2009). In addition, unlike most previous studies, this paper distinguishes two types of R&D expenditures and examines their individual association with innovation. We then separate internal (intramural) R&D from external R&D (acquisition of external technologies and knowledge). The second originality is related to the distinction between product, process and organizational innovations and innovative sales introduced as four separate measures of innovation outputs. This is different from Crépon et al. (1998) who introduced patent numbers as one measure of innovation output. The main hypothesis here is that different measures of ICT use and R&D activities should lead to significant differences in determining technological innovation outputs, as measured by the introduction of new and improved products, processes and innovative sales, and non-technological innovation outputs, as defined as the introduction of new or improved organizational methods, across the innovation process (Nguyen Thi and Mothe, 2008).

The paper is organized as follows. We first outline the dataset, variables, based on the large-scale fourth Community Innovation Survey (CIS2006) and the "ICT Usage and E-commerce in Enterprises Survey", both carried out in Luxembourg (Section 2). We then present the methodology used in the paper (Section 3). In Section 4 we present and discuss the estimation results. Based on these considerations, we conclude with derived implications for policy-makers and provide avenues for further research (Section 5).

2. Data

2.1. Data set

We used two large and nationally representative datasets of Luxembourg manufacturing and services firms, collected by the CEPS/INSTEAD[1] in collaboration with STATEC[2]. The first dataset is drawn from the "Community Innovation Survey" (CIS2006) carried out in 2008. The objective is to collect data on firms' innovation behaviour, over the three-year period from 2004 to 2006, according to the OECD recommendations published in the Oslo manual

[1]Centre d'Etudes, de Populations, de Pauvreté et de Politiques Socio-Economiques/International Network for Studies in Technology, Environment, Alternatives, Development.

[2]Central Service of Statistics and Economic Studies.

(OECD/Eurostat, 2005). It provides a set of firms' general information (sector of activities, group belonging, number of employees, sales, geographic market), information about technological and non-technological innovation as well as perceptions of factors hampering innovation activities or subjective evaluation of the effects of innovation. The dataset also comprises information about sources of information and characteristics of concurrence of the market in which firm involves. The sample contains 568 representative firms of least 10 employees in the manufacturing and the service sectors.

The second firm-level dataset is taken from the annual "ICT Usage and E-commerce in Enterprises Survey" realized in 2005 and 2006 for the ICT use during respectively 2004 and 2005. These annual surveys were conducted by post mail addressing to about 2500 firms employing 10 persons and more and operating in all sectors of the economy. The response rate is around 60%. Questionnaires collect information on the use of firms' characteristics, investments and use of different ICT.

When merging these two samples, we obtained a final sample of 364 representative firms. An important advantage of the data set we use is that we have a large set of information on ICT use allowing us to control for differences of ICT capital stocks in determining technological and non technological innovation outputs.

2.2. Variables and statistic

2.2.1. Indicators of ICT use

To capture the degree of variety and sophistication of ICT, a large set of variables on the ICT use are used: intranet, extranet, video-conference, electronic forum, group project, e-commerce (online purchases and online sales) and software to manage orders (cf. Table 5 in the Appendix for descriptive statistics).

Intranet is defined as the use or not of an internal communications network within the firm using Internet protocol. Group project is the presence or not of a platform allowing collaborative group's members to efficiently and effectively manage time and agenda. Extranet is the use or not of a secure extension of an Intranet that allows external users to access some parts of an organization's Intranet. Video-conference is the use or not of a network of communication that permits to see and talk to the caller. Electronic forum is the use or not of a tool or service allowing sharing comments and discussions on a common subject or project.

ICT like Intranet or group project are tools dedicated to internal communication and they can be used to increase collaboration between employees. Conversely, Extranet and vide-conference use are tools dedicated to external communication and they can be mobilized by firms to organize collaborations with partners. Electronic forum can be used internally or externally.

Similar to van Leeuwen and Farooqui (2008) and Polder et al. (2009), we also include the number of software applications to manage orders to capture the degree of sophistication of ICT. Software contains different tools to manage orders such as internal system for re-ordering replacement supplies; invoicing and payment systems; system for managing production, logistics or service operations; suppliers' business systems (for suppliers outside the enterprise group) or customers' business systems (for customers outside the enterprise group).

The investment in such ICT is a measure of firms' investment in the optimization of their business processes in order to increase the efficiency to rapidly respond to the orders of the demand.

The use of computer-network to sell or purchase products and services can be viewed as a sign of an advanced process of reorganization of production and logistics processes to meet fast times to the customers in order to be competitive. In order to capture the effect of this technological advancement, we use the binary variable "E-commerce" (online purchases and online sales) which is defined as the fact of having done at least one transaction that is conducted over Internet protocol-based networks and over other computer-mediated networks. The goods and services are ordered over those networks, but the payment and the ultimate delivery of the good or service may be conducted on- or off-line. Orders received via telephone, facsimile, or manually typed e-mails are not counted as electronic commerce.

In addition, in order to control for the use of ICT at time t (our period of reference), we use a set of ICT variables but collected at time $t-1$ and at the sector/size levels (or the town-level): Intranet usage in the sector in $t-1$; Extranet usage in the sector in $t-1$; Video-conference usage in the sector in $t-1$; Electronic forum usage in the sector in $t-1$; Group project usage in the sector in $t-1$; DSL usage in the sector in $t-1$; Knowledge of the Law for electronic signature in the sector in $t-1$; Knowledge of the National Certification Office in the sector in $t-1$; Software usage in the town in $t-1$; Online purchases in the sector in $t-1$; Online sales in the sector in $t-1$.

2.2.2. R&D activities

The R&D efforts are represented through two innovation activities performed by firms during the three years 2004 to 2006: (1) in-house R&D, (2) external R&D and acquisition of technologies and knowledge (henceforth called 'external R&D'). Firms which have introduced products or processes innovations are asked whether they have engaged in internal and external R&D activities. Thanks to this information, we determine two binary variables: *firm's probability to invest in internal R&D* and *firm's probability to invest in external R&D*. The *internal and external R&D intensities* are then defined as the ratio of R&D expenditures per employee for firms who reported engagement in R&D activities at the time of the survey.

2.2.3. Innovation variables

We use four indicators of innovation outputs. The first one, *product innovation*, is defined as the probability of introducing new or significantly improved goods or/and services during the three years from 2004 to 2006. The second one, *process innovation*, is the probability of introducing new or significantly improved processes during the three years from 2004 to 2006. The third one, *organizational innovation*, is the probability of introducing at least one of the four organizational practices: new business practices; new knowledge management systems; new methods of workplace organization and/or new methods of organizing external relations. Finally, the *innovative performance* is measured as the percentage of total turnover from product innovations that are new to the firm (see Table 5 in the Appendix for descriptive statistics).

In the questionnaire, firms are asked to evaluate the importance of obstacles to innovation. We constructed three dummy variables according to the obstacles' importance: (1) *cost-related obstacles* taking the value 1 if the scores of importance of lack of funds or/and high costs of innovation is crucial; (2) *knowledge-related obstacles* taking the value 1 if the scores of importance of lack of qualified personnel or/and lack of information on technology or on market or/and difficulty in finding cooperation partners is crucial; (3) *market-related obstacles* taking the value 1 if the scores of importance of uncertainty of products demand or/and dominance of established firms is crucial.

The data also allows determining different motivations for firms' innovation efforts. In the questionnaire, firms rated the importance of products or processes innovation effects on a Likert scale (0 to 3). Similarly to Belderbos et al. (2004), we generate the *cost-push* variable by summing the scores of cost-related objectives such as improved flexibility, increased capacity of production, reduced labor costs, materials or energy. Then, we rescaled the total score to a number between 0 and 1. The *demand-pull* variable is generated in a similar way, summing scores of demand-related objectives such as increased range of products, increased market share or improved quality of products. The sum is then rescaled between 0 and 1.

Strategic protection is a binary variable, equal to 1 if the score of importance of strategic protection method "secrecy" or "complexity of design" or "lead-time advantage on competitors" is "crucial", 0 otherwise. *Formal protection* is equal to 1 if the score of importance of formal protection method "patent" or "trademarks" or "registration of design patterns" or "copyrights" is "crucial", 0 otherwise. Five binary variables of R&D cooperation are also included: *cooperation with clients, suppliers, competitors, public institutes* (Universities or other higher education institutions or government or public research institutes) and *private institutes* (consultants, commercial laboratories or private R&D institutes).

Among the control variables, firm size is measured by the natural logarithm of the number of employees. We also introduced a dummy variable of group belonging, taking the value 1 if the firm belongs to a group, 0 otherwise. A sector dummy variable is used: services and industry (reference).

Otherwise, firms are also asked to rate the degree of competition of the market on a Likert scale from 0 (no effective competition) to 3 (very intensive). Thanks to this information, we construct the variable "*competition intensity*". *Physical capital* is defined as the amount of expenditures for acquisition of advanced machinery, equipment and software to produce new or significantly improved products and processes. *Labour productivity* is the natural logarithm of value-added per employee at the moment of the survey.

3. Methodology

A CDM model extended to ICT usage is used. Concretely, we perform a three-step analysis. Each step required a different econometric treatment depending on the characteristics of the data.

3.1. Innovation inputs equations

In the first step, we attempt to assess the determinants of two innovation inputs considered in the model: ICT use and R&D expenditures.

3.1.1. ICT use

We model ICT use of the firm through qualitative data that covers a large part of the usage a firm can made with ICT: internal and external communication, improvement of the efficiency of the business process and e-commerce use (e-purchases and e-sales). Software applications to manage orders are also included.

The first group of variables is dichotomous variables and can be estimated with a multivariate Probit model assuming that the error terms are multivariate normal with correlations coefficients between the various equations estimating ICT use. The number of software applications is a score and looking at it distribution in the sample suggest to consider this variable as a count variable with a spike of zeros. For seven ICT measures considered, we have dichotomous variables Y_{ictj} with $j = 1, \ldots, 7$ according to the ICT use modelled. These dichotomous variables Y_{ictj} are associated with latent variables such as[3]:

$$Y^*_{ictj} = \beta'_j X_{ict} + \gamma'_j X_{charac.} + \epsilon_j \qquad (1)$$

and $Y_{ictj} = 1 \qquad$ if $Y^*_{ictj} > 0$ and 0 otherwise.

[3]We don't introduce a firm subscript in order to avoid notational clutter.

Where Y^*_{ictj} are unobserved latent variables, X_{ict} a vector of variables that are ICT instruments, β the associated vector of parameters and $X_{charac.}$ a vector of explanatory variables about firms' characteristics, γ the associated vector of parameters. ϵ_j are error terms distributed as multivariate normal, each with a mean of zero, and variance-covariance matrix with the value 1 on leading diagonal and correlations $\rho_{kl} = \rho_{lk}$ as off-diagonal elements.

As the score of software includes a large number of zeros, to take account of a possible bias related to zero, a Zero-Inflated negative binomial (ZINB) model is estimated with ICT instruments and firms characteristics like the estimates of other ICT uses.

For firms whose score is nil (Y^*_{ictj}=0), zero can come from two regimes. In one of the regimes the result is always 0 (regime 1). This zero can be due to the fact that firms have no willingness to develop use such software. The score will therefore always be zero. In the other regime (regime 2), the zero is being generated by a negative binomial distribution. This process generates both 0 values and positive values for firms that use software for the management of orders. The zeros, in the regime 2, may be due to the fact that the firm, even if it has the characteristics to use such software, has no usage at the time of observation. The probability that the value of Y_{ictj} (with $j = 8$ the eighth ICT variable) is created by the regime 1 is noted p and the probability that the value of Y_{ictj} is created by the regime 2 is noted $(1 - p)$. The probability p can be modelled as $p = F(\gamma' z)$, with F the distribution function of the Logistic Law and z a set of variables distinguishing firms with a score that is always 0 from others with a score that takes positive values or zero. The probability of observing Y_{ictj} ($Prob(Y_{ictj} = y_{ictj}|xi$, regime 2)) is estimated by a negative binomial distribution.

Then, the probability of observing Y_{ictj} is:
$Prob(Y_{ictj} = 0|x) = Prob(\text{regime 1}) + Prob(Y_{ictj} = 0|x,\text{regime 2})Prob(\text{regime 2})$
$Prob(Y_{ictj} = Y_{ictj}|x) = Prob(Y_{ictj} = y_{ictj}|x,\text{regime 2})Prob(\text{regime 2})$ with $y_{ictj} = 1, 2, \ldots$

3.1.2. R&D expenditures

As for the R&D expenditures, we distinguish two types of R&D activities, internal and external R&D instead of one aggregated indicator of R&D expenditures. It is in order to evaluate separately their effects on innovation outputs.

For any firm i, we can write the following model of R&D investment:

$$Y^*_{RDEXPki} = \beta'_{ki} X_{charac.} + \epsilon_{RDEXPki} \quad (2)$$

Where $Y^*_{RDEXPki}$ is the latent variable for internal R&D expenditures when $k = 1$ and for external R&D expenditures (when $k = 2$), $X_{charac.}$ a vector of explanatory variables relating firms' characteristics that may influence R&D effort, β the associated vector of parameters and $\epsilon_{RDEXPki}$ the error term.

However, we only observe R&D expenditures when firms declare to invest in R&D. We therefore estimate a selection model describing whether a firm is doing R&D or not (internal and external).

The selection equation is given by:

$$Y_{RDki} = \begin{cases} 1 & \text{if} \quad Y^*_{RDki} = \delta'_{ki} w_i + \epsilon_{RDki} > c \\ 0 & \text{if} \quad Y^*_{RDki} = \delta'_{ki} w_i + \epsilon_{RDki} \leq c \end{cases} \tag{3}$$

Where Y_{RDki} is the observed binary variable being 0 for non R&D and one for R&D reporting firms and w_i is a vector of variables explaining the R&D decision. Firms report R&D expenditures only if the corresponding latent variable Y^*_{RDki} is above a certain threshold level c.

On condition that firm i reports R&D activities, the amount of resources invested in R&D is given by:

$$Y^*_{RDEXPki} \quad | \quad Y^*_{RDki} > c = \beta'_{ki} X_{charac.} + \epsilon_{ki} \tag{4}$$

The error terms ϵ_{ki} and ϵ_{RDki} are assumed to be bivariate normal with zero mean, variance $\sigma^2_{\epsilon_{RDEXPki}} = 1$ and $\sigma_{\epsilon_{RDki}}$ and correlation coefficient $\rho\epsilon_{RDki}\epsilon_{RDEXPki}$.

As dependent variables $Y_{RDEXPki}$ and Y_{RDki} are respectively the expenditures in R&D and the probability to do R&D or not, consistent estimates for the parameters of interest can be obtained by maximum likelihood estimation of a generalized Tobit that accounts for censoring in R&D investment. The inverse Mill's ratio included in the model for correcting left-censoring is not significant. This indicates that the estimation results for the investment in R&D are not influenced by censoring.

3.2. Innovation outputs equations

In the second step, the second stage of the model concerns the innovation outputs. We attempt to investigate the impact of the predicted R&D intensity and ICT use as innovation inputs on innovation outputs. At this step, four innovation outputs are considered as dependent variables: product innovation, process innovation, organizational innovation and firm's innovative performance defined as the percentage of total turnover from product innovations that are new to the firm. The predicted R&D intensity and the predicted binary ICT use issue from the first stage estimation are included in these equations as explanatory variables.

As the three first variables are binary, a trivariate Probit is performed. Similar to Robin and Mairesse (2009), we take into account the fact that the different innovation outputs can be jointly determined. The model is:

$$Y^*_{innop} = \beta'_p \widehat{X}_{ict} + \gamma'_p \widehat{X}_{rd} + \delta'_p X_{charac.} + \epsilon_p \tag{5}$$

and $Y_{innop} = 1$ if $Y^*_{innop} > 0$ and 0 otherwise

Where Y^*_{innop} with $p = 1, 2$ or 3 according to the innovation output considered are unobserved latent variables that describe innovation outputs, $\widehat{X}_{ict}$ are the predicted ICT use, $\widehat{X}_{rd}$ are the predicted value of internal and external R&D expenditures, $X_{charac.}$ a vector of explanatory variables about firms' characteristics, and β, γ, δ their respective associated vector of parameters. ϵ_p are error terms distributed as multivariate normal, each with a mean of zero, and variance-covariance matrix with the value 1 on leading diagonal and correlations $\rho_{kl} = \rho_{lk}$ as off-diagonal elements.

As for the innovative performance which is the percentage of total turnover from innovative products, we use a generalized linear model with a Logit transformation. Since this variable is a proportion, we use this maximum likelihood estimator. It conduct us to estimate a logit transformed form of the variables as $\ln(Y_{innop}/(1 - Y_{innop}))$, the log of the odds of Y_{innop} (with $p = 4$ for the innovative performance). The model is estimated with the same explanatory variables as for innovation outputs (the predicted ICT use, the predicted value of internal and external R&D expenditures and a vector of explanatory variables about firms' characteristics).

By using the predicted value of internal and external R&D expenditures and the prediction of ICT use, we instrument the R&D effort and firms' investment in ICT and thus we take into account the fact that innovation inputs could be endogenous to the innovation production functions. Thus we take into account the fact that unobservable characteristics could increase both the investment in R&D, the investment in ICT and the innovative behaviour of the firm. If it is the case Y_{RDki} , Y^*_{ictj} and the error term of the innovative performance regression would be positively correlated and the parameters would be biased upward. Using predicted value from the investment in R&D and in ICT correct for this as long as the coefficient of explanatory variables in the regression of ICT use and R&D expenditures are independent of the error term.

3.3. Labour productivity equation

The third step consists in estimating an augmented production function to analyze the impact of innovation outputs on labour productivity measured as the natural logarithm of value-added per employee. Concretely, we perform a Tobit model which considers the predicted innovation outputs from the second-step regression as explanatory variables.

The estimation model of firm's labour productivity is:

$$\ln(Y_{productivity}) = \beta_p' \widehat{Y}_{innop} + \gamma' X_{charac.} + \mu \tag{6}$$

Depending on the regression, we have $\widehat{Y}_{inno1}$ that is the marginal success probability of doing product innovation, $\widehat{Y}_{inno2}$ those of doing process innovation, $\widehat{Y}_{inno3}$ those of doing organizational innovation, $\widehat{Y}_{inno4}$ the predicted value of innovative performance, β_1, β_2, β_3, β_4 their respective associated vector of parameters. $X_{charac.}$ is a vector of explanatory variables about firms' characteristics, γ the associated vector of parameters and μ the error term.

Using the prediction of our previous stage allow us to control for the potential endogeneity of innovation outputs in the estimation of the labour productivity of the firm.

4. Estimation results

4.1. Determinants of ICT use and R&D activities

The estimation results of our first step for ICT use and R&D activities are presented in Tables 1 and 2. Results for software to manage orders as dependent variable are presented in Table 6 in the Appendix. For ICT use, we find significant differences in the determinants of different measures of ICT used in the model. Belonging to a group affects, for example, positively the probability of firm to adopt intranet and extranet, while not for e-commerce or electronic project management. Firm size is positive and significant for the probability to adopt extranet and e-commerce. This result is consistent with the belief that the implementation of new technology is closely associated with the firm size since larger firms are more likely to adopt a new technology due the extended range of commercial activities as well as the risks and costs involved with the adoption which are lower, as shown in Davies (1979), Bertschek and Fryges (2005) and Gretton, Gali, and Parham (2002).

Table 1: Estimation results for ICT use

	Intranet	**Extranet**	**Video-conf.**	**Electronic forum**	**Group project**	**Online purchases**	**Online sales**
Firm size	0.116	0.261**	-0.139	-0.093	0.316**	0.191	0.386**
	(0.133)	(0.133)	(0.170)	(0.165)	(0.143)	(0.126)	(0.179)
Services sector	0.049	-0.036	0.079	0.555	0.264	-0.156	0.269
	(0.305)	(0.294)	(0.386)	(0.354)	(0.330)	(0.283)	(0.382)
Group	0.676***	0.503**	0.065	0.354	0.165	-0.05	-0.081
	(0.235)	(0.221)	(0.278)	(0.276)	(0.247)	(0.202)	(0.205)
Intranet usage	0.849	0.484	0.692	0.585	0.485	1.788*	1.092
in the sector in t-1	(1.466)	(0.992)	(1.066)	(1.138)	(1.438)	(1.067)	(0.924)
Extranet usage	-0.829	-1.488	4.431**	2.243	1.105	-1.569	0.443
in the sector in t-1	(1.680)	(1.614)	(1.981)	(2.016)	(1.739)	(1.540)	(1.651)
Video-conference usage	2.712**	-1.553	0.937	1.43	0.434	-0.719	-1.158
in the sector in t-1	(1.125)	(1.310)	(1.475)	(1.402)	(1.646)	(1.345)	(1.965)
Electronic forum usage	-0.974	-0.769	-1.619	0.679	-0.552	1.045	-2.797**
in the sector in t-1	(1.637)	(1.112)	(1.240)	(1.281)	(1.244)	(1.312)	(1.364)
Group project usage	-0.019	0.319	1.147	1.485	2.033	1.187	-0.233
in the sector in t-1	(1.796)	(1.204)	(1.373)	(1.301)	(1.356)	(1.243)	(1.689)
DSL usage	0.719	-0.181	1.974**	1.19	2.314**	-0.618	-0.076
in the sector in t-1	(1.193)	(0.914)	(0.955)	(0.909)	(1.080)	(0.912)	(1.276)
Know. the Law for	1.449	2.468**	-0.265	-0.849	0.147	0.64	0.748
e-signature (sector,t-1)	(1.295)	(1.148)	(1.340)	(1.297)	(1.430)	(1.021)	(1.258)
Know. the Nat. Certif.	0.63	2.293	-1.851	-3.217**	0.775	0.372	-0.605
Office (sector,t-1)	(1.685)	(1.445)	(1.684)	(1.557)	(1.603)	(1.478)	(2.760)
Software usage	0.618	0.366	-0.759	-0.491	-0.102	0.417	0.911*
in the town in t-1	(0.455)	(0.455)	(0.619)	(0.642)	(0.532)	(0.424)	(0.491)
Online purchases	0.262	0.725	-0.916	-0.542	-1.803	0.694	-3.015**
in the sector in t-1	(1.280)	(1.127)	(1.318)	(1.326)	(1.469)	(1.093)	(1.451)
Online sales	-1.554	-0.22	-1.165	-1.964*	-1.719*	-0.319	1.521
in the sector in t-1	(1.087)	(0.836)	(0.960)	(1.039)	(0.922)	(0.854)	(0.944)
Constant	-1.837***	-2.618***	-2.381***	-1.929**	-3.646***	-1.686***	-2.612***
	(0.681)	(0.699)	(0.868)	(0.871)	(0.991)	(0.640)	(0.677)
# obs.	364						
Log pseudolikelihood	-1121.8442						
Wald chi2 (98)	583.26***						

Note: * significant at 10%; ** significant at 5%;*** significant at 1%.
Robust standard errors in parentheses.

Table 2: Estimation results for R&D

Selection equation	**Internal R&D Internal R&D**	**External R&D External R&D**
Strategic	-0.069	0.252
protection	(0.311)	(0.311)
Formal	0.720***	0.422**
protection	-(0.239)	-(0.208)
Services	-0.389**	-0.221
sector	(0.193)	(0.212)
Size: 50-249	0.123	0.088
	(0.195)	(0.195)
Size: > 249	1.235***	0.705***
	(0.231)	(0.245)
Group	-0.18	0.653***
	(0.208)	(0.190)
Constant	-0.827***	-1.246***
	(0.189)	(0.237)
Intensity equation	**Internal R&D intensity**	**External R&D intensity**
Cooperation with	0.07	0.224
clients	(0.566)	(0.705)
Cooperation with	-0.862**	0.066
suppliers	(0.405)	(0.471)
Cooperation with	0.571	-0.508
competitors	(0.657)	(0.520)
Cooperation with	1.136**	-0.98
public institutes	(0.465)	(0.662)
Cooperation with	-0.009	1.024**
private institutes	(0.414)	(0.467)
Strategic	-0.366	-1.292**
protection	(0.554)	(0.555)
Formal	1.324***	-0.028
protection	(0.513)	(0.527)
Services	0.453	0.829**
sector	(0.533)	(0.371)
Size: 50-249	-1.395**	-0.596
	(0.548)	(0.481)
Size: > 249	-0.833	-1.070**
	(0.875)	(0.525)
Group	0.7	1.539***
	(0.451)	(0.571)
Cost-push	-0.228	-0.689
	(0.383)	(0.551)
Demand-pull	-0.112	-0.164
	(0.429)	(0.530)
Constant	6.714***	7.593***
	(1.005)	(1.401)
# obs.	364	364
Log pseudolikelihood	-304.1051	-321.4292
Wald chi2 (13)	38.18***	84.14***

Note: * significant at 10%; ** significant at 5%;*** significant at 1%.
Robust standard errors in parentheses.

As for the R&D activities, we distinguish two types of activities: in-house R&D and external R&D and technological acquisition. Results are presented in Table 2. As for the Probit part of the Tobit generalized model for whether firms engage in internal and external R&D or not, results show that being part of a group matters for external R&D, while not for in-house R&D. The analysis of R&D intensity shows a significant and positive effect of cooperation with public research organizations (University, higher education institutions, government or public research institutes) on the in-house R&D intensity, while no such evidence is found for external R&D and technological acquisition. On the contrary, the allocation of external R&D resources appears to be positively determined by the fact that firm engages in R&D cooperation with private research organizations such as consultants, commercial laboratories or private R&D institutes. Surprisingly, cooperation with suppliers is negatively associated with internal R&D intensity. This result is unexpected but could be explained by the fact that firms use cooperation with suppliers mainly for cost reduction. They are thus likely to focus less attention on other important aspects of innovation processes. Among the set of control variables, firm size has negative and significant impact on both internal and external R&D intensities. Recall that our results also show that firm size affects both in-house and external R&D positively, corroborating previous empirical literature (Benavente, 2006; Crépon et al., 1998). That is, large firm has a higher probability to enrol in R&D activities but the amount of R&D resources decreases with size. This result could be explained by the fact that while large firms are more active than small firms in R&D activities for diversifying its technological activities or reinforcing its position on the market, large firms could allocate fewer resources in R&D activities since they have in-house financial resources and competencies which could allow them to maximize their investment in R&D activities by reducing its expenditures. We also find that neither demand-pull nor cost-push variables have significant effect on the internal and external R&D intensities. That is, the firm's allocation of R&D resources neither associated with technological opportunities nor with market demands.

4.2. Effects of ICT use and R&D expenditures on innovation output

Regarding the innovation output equations in the second step, results are presented in Table 3. In this part, we make use of four measures of innovation outputs: product innovation, process innovation, organizational innovation and innovative performance, measured as the percentage of total turnover from product innovations that are new to the firm. About the effects of R&D expenditures on innovation output, notice that previous empirical studies on the relationship between innovation and productivity do not distinguish internal and external R&D. In our analysis, we attempt to make this distinction. The main hypothesis is that there are significant differences in the way in which internal and external R&D are related to the introduction of different types of innovations. Indeed, our model shows that the probability of introducing product innovation is higher for firms that invest intensively in either internal or external R&D. This is in line with previous empirical findings indicating the crucial role of R&D investments in the innovation process as it conditions knowledge creation as well as firms' capacity to absorb external knowledge. This result confirms the acknowledged role of R&D expenditures in enhancing technological innovation, as largely documented in the literature (Crépon et al., 1998; Parisi et al., 2006; Polder et al., 2009). Innovative performance, process and organizational innovations are significantly influenced positively only by external R&D. These important results provide support to the idea that internal R&D may be helpful in allowing firms to absorb new technologies and knowledge which are necessary for introducing technological innovation whereas external R&D and acquisition of new technologies and knowledge only creates a necessary condition for the introduction of a new process or organizational change (Conte and Vivarelli, 2005).

Among the set of control variables, firm size and belonging to a group are not significant for all innovation output. Firms using formal methods of innovation protection have a higher probability of introducing technological and non technological innovations. The perception of costs-related obstacles to innovation is positively associated with the measures of technological innovation output. This indicates that cost reduction is considered as an important objective of firm's innovation activities due to economies of scale and learning-by-doing effects. By contrast, the perception of market-related obstacles has significant and negative impact on the introduction of organizational innovation. In other words, when the market is dominated by well established firms and by the uncertainty of demand for innovative goods and services, firms tend to focus less often on implementation of a new organizational method in firm's business practices, knowledge management, workplace organization or external relations. An interesting result indicates that firms who claimed to be in a highly competitive market have a higher probability of introducing new organizational methods. By contrast, competition is not important for explaining the probability of introducing product, process innovation and innovative performance. This result is not in accordance with the well established idea that the incentive of competition is a key driver of innovation. That is, firms being in a high competitive market should introduce more innovation activities compared to firms acting mainly on less competitive markets (Baldwin and Scott, 1987; Kamien and Schwartz, 1982; Cohen and Levin, 1989).

Table 3: Estimation results for innovation outputs

	Product innovation	**Process innovation**	**Organizational innovation**	**Innovative performance**
Predicted R&D intensities				
External R&D intensity	0.189***	0.086***	0.094***	0.098***
	(0.040)	(0.028)	(0.034)	(0.031)
Internal R&D intensity	0.163***	0.01	0.016	0.04
	(0.042)	(0.036)	(0.037)	(0.042)
Predicted ICT uses				
Software	0.201	0.155	0.374**	-0.148
	(0.215)	(0.200)	(0.189)	(0.295)
Intranet	0.852***	0.023	0.388	0.745**
	(0.329)	(0.275)	(0.282)	(0.354)
Extranet	-0.577*	-0.048	-0.065	-0.161
	(0.304)	(0.293)	(0.307)	(0.483)
Video-conference	-0.284	0.227	-0.447	-0.157
	(0.622)	(0.685)	(0.658)	(0.538)
Electronic forum	0.391	-0.882**	0.8	-0.108
	(0.642)	(0.442)	(0.561)	(0.641)
Group project	0.794**	0.711*	0.766**	0.418
	(0.363)	(0.417)	(0.373)	(0.628)
E-commerce-online purchases	-0.465	-0.103	-0.22	-0.699**
	(0.285)	(0.217)	(0.225)	(0.339)
E-commerce-online sales	1.020**	0.445	-0.43	0.799*
	(0.477)	(0.367)	(0.419)	(0.423)
Other explanatory variables				
Services	0.226	-0.257	0.325	-0.377
	(0.323)	(0.278)	(0.263)	(0.438)
Size: 50-249	0.221	0.217	-0.413	0.44
	(0.306)	(0.263)	(0.253)	(0.438)
Size: > 249	-0.415	-0.238	0	-0.023
	(0.523)	(0.471)	(0.477)	(0.610)
Group	-0.104	0.316	-0.092	-0.07
	(0.277)	(0.240)	(0.263)	(0.248)
Cost-related obstacles	0.833***	0.581*	0.424	0.681**
	(0.300)	(0.297)	(0.259)	(0.274)
Knowledge-related obstacles	-0.018	0.545**	0.391	-0.064
	(0.288)	(0.262)	(0.268)	(0.282)
Market-related obstacles	-0.109	-0.068	-0.696***	0.197
	(0.252)	(0.240)	(0.231)	(0.283)
Strategic protection	0.264	0.063	-0.085	-0.005
	(0.266)	(0.237)	(0.282)	(0.267)
Formal protectionăă	0.569**	0.425*	0.530**	0.446
	(0.240)	(0.222)	(0.217)	(0.285)
Competition intensity	0.085	0.017	0.227*	0.089
	(0.125)	(0.146)	(0.125)	(0.198)
Constant	-2.073***	-1.454**	-1.715***	-4.041***
	(0.508)	(0.613)	(0.524)	(0.694)
# obs.		364		364
Log likelihood		-54.4958		-533.907

Note: * significant at 10%; ** significant at 5%;*** significant at 1%.
Robust standard errors in parentheses.

Concerning the relationship between ICT use and innovation outputs, we find support for the assumption that ICT is an “enabler of innovation”, which is in line with those previously found in the literature, albeit we define ICT in more detail, by dividing them into different types such as intranet, extranet, software, e-commerce, etc. instead of building an aggregated indicator of ICT use. That makes possible to capture the direct effects of different types of ICT on different measures of innovation outputs. The use of internal ICT tools for facilitating communication such as electronic group project affects positively the probability to introduce product, process and organizational innovations. Moreover, Intranet leads to higher probability of product innovation and higher innovative performance but there are no statistically significant process and organizational innovation effects. The use of ICT tools that favour external communications like Extranet has a negative effect for product innovation. A negative effect is also observed for process innovation with respect to the use of electronic forum. For the investment in software, that is a sign of a will to optimize processes, we find that this investment is significantly associated to the probability of introducing new organizational methods inside the firm, while it has no impact on other innovation outputs. The use of e-commerce for selling products and services that is a measure of optimized production and logistics processes significantly increases the probability of product innovation, as well as, enhances the innovative performance.

4.3. Effects of innovation outputs on labour productivity

Table 4: Estimation results for labour productivity

Predicted innovation outputs				
Product innovation	0.268			
	(0.265)			
Process innovation		0.384		
		(0.394)		
Organizational innovation			0.743*	
			(0.419)	
Innovative performance				4.156**
				(1.990)
Other explanatory variables				
Size: 50-249	0.093	0.078	0.148	0.079
	(0.165)	(0.186)	(0.157)	(0.178)
Size: > 249	-0.036	-0.054	-0.114	0.018
	(0.185)	(0.188)	(0.198)	(0.159)
Group	0.675***	0.646***	0.632***	0.613***
	(0.170)	(0.182)	(0.169)	(0.170)
Services sector	0.266**	0.289**	0.230**	0.273**
	(0.121)	(0.123)	(0.117)	(0.123)
Physical capital	0.023	0.025	0.02	0.018
	(0.014)	(0.015)	(0.016)	(0.015)
Competition intensity	0.087	0.077	0.044	0.059
	(0.077)	(0.074)	(0.080)	(0.076)
Cost-related obstacles	-0.314	-0.326	-0.351*	-0.379*
	(0.209)	(0.218)	(0.208)	(0.217)
Knowledge-related obstacles	-0.149	-0.205	-0.29	-0.101
	(0.184)	(0.197)	(0.192)	(0.188)
Market-related obstacles	-0.113	-0.101	0.047	-0.144
	(0.207)	(0.208)	(0.214)	(0.204)
Constant	11.211***	11.247***	11.138***	11.281***
	(0.298)	(0.278)	(0.313)	(0.280)
# obs.	364	364	364	364
Log likelihood	-536.016	-536.19	-534.756	-533.907
Wald chi2 (10)	78.42***	105.96***	81.19***	116.63***

Note: * significant at 10%; ** significant at 5%;*** significant at 1%.
Robust standard errors in parentheses.

Results of the third-stage estimation on the relation between predicted innovation outputs and labour productivity are presented in Table 4. The first important result pertains to the impact of predicted innovative performance to labour productivity, while predicted product innovation has no significant effect once controlled by ICT use and R&D expenditures. The absence of such a relation between product innovation and productivity may be due to the substantial time lag usually associated with the return on investment of such a long-term strategy. When introducing new goods or services, firm is involved in a long-term process of customization and commercialization which do not immediately result in substantial improvement in labour productivity. The productivity effect of product innovation could appears only at the moment of its commercial success, expressed here by "innovative performance", measured as the turnover percentage of sales generated from new or improved products.

As expected, our results also show that organizational innovation once controlled for ICT use is a crucial issue for labour productivity. This result is consistent with the widespread belief that implementing new organizational methods, conditional to ICT use, could result in improvements in organizational flexibility which in turn leads to improved firm efficiency and productivity by reducing costs and by enabling firms to improve product quality in the form of new products or in improvements in intangibles aspects of existing products (Bresnahan et al., 2002; Brynjolfsson and Hitt, 2000). With respect to the process innovation, the results indicate that there is no significant impact of this innovation output on labour productivity. This is in line with previous empirical studies that follow a similar structural approach to the assessment of the relationship between innovation and productivity (Roper et al., 2008; Peters, 2008). However, note that many empirical studies also provide evidence of a strong and positive relationship between process innovation and productivity, as shown in Polder et al. (2009), Robin and Mairesse (2009), Mairesse et al. (2009) or Parisi et al. (2006). Another results show that the labour productivity is positively and strongly related to the fact that firm belongs to a group. There is no direct firm size effect on the labour productivity. We find no effect of physical capital on firm productivity.

5. Conclusion

This paper raises the question of the relationship between innovation and productivity during the innovation process. Concretely, we wonder whether R&D activities and ICT use as innovation inputs play a role in determining the probability of introducing technological and non technological innovations and whether these innovation outputs conditional to ICT use and R&D lead, in turn, to an improvement of labour productivity. Similarly to Crépon et al. (1998), our robust three-step estimations underline the benefits of taking into account the joint endogeneity of the key variables of the whole system. In this adaptation of CDM model extended with ICT use, we consider a four equations model that relates labour productivity to innovation outputs, innovation outputs to R&D and ICT use, and R&D and ICT use to their determinants. Unlike the previous empirical literature, we introduce in the model a larger set of indicators of ICT use and distinguish two types of R&D activities, internal and external R&D instead of constituting aggregated measures of ICT use and R&D.

In the case of Luxembourg, results show that firm size affects positively firm decision to invest in internal and external, but negatively the intensity of its investments. Positive effect of firm size is also significantly associated to the adoption of some measures of ICT use such as extranet and e-commerce, suggesting that large firms do not invest in a systematic way in all types of ICT.

Looking at the relationship between ICT use, R&D expenditures and innovation outputs, results confirm an expected observation that internal and external R&D expenditures are an important driver of technological innovation (i.e. product innovation and innovative performance), while external R&D only fosters process and organizational innovation. Regarding the benefits of different measures of ICT use, the model shows controversial results. Indeed, while intranet and e-commerce are strongly associated to product innovation and innovative performance, using these ICT platforms does not have any impact on process and organizational innovations. In addition, the probability of introducing product innovation is smaller for firm adopting extranet. These unexpected results might be, however, explained by the fact that some investment in ICT can substitute for use of other forms of capital, which leads, at least in short-term, to a decrease of innovation activities. All in all, while confirming the acknowledged 'innovation-enabler' role of some ICT, these results point out the fact that not all increases in ICT investments translate into equivalent increase in firm capacity to introduce new products/processes or in an improvement of innovative performance.

Results also indicate that labour productivity is positively associated to technological innovation conditional to R&D expenditures and ICT use, but it is only indirectly via the impact of innovative performance on productivity. Furthermore, the results also strongly suggest that organizational innovation once controlled for ICT use is a crucial issue for labour productivity. This is in line with the hypothesis that new or improved organizational arrangements, enabled by ICT platforms, lead to a subsequent improvement of product quality, timeliness, reduce waste, transactions and coordination costs, which could, in turn, result in an improvement of the labour productivity.

Appendix

Table 5: Descriptive statistics for main variables used in the models

Dependent variables	# obs.	Mean	St. dev.	Explanatory variables	# obs.	Mean	St. dev.
Intranet	364	0.62	0.486	Firm size	364	3.533	0.987
Extranet	364	0.371	0.484	Group	364	0.498	0.501
Video-conference	364	0.152	0.36	Services	364	0.784	0.412
Electronic forum	364	0.162	0.369	Physical capital	364	4.301	5.889
Group project	364	0.237	0.426	Cost-related obstacles	364	0.134	0.341
Online purchases	364	0.509	0.5	Knowledge-related obstacles	364	0.24	0.427
Online sales	364	0.231	0.422	Market-related obstacles	364	0.219	0.414
Software to manage orders	364	1.07	1.386	Strategic protection	364	0.136	0.343
Internal R&D	364	0.217	0.413	Formal protection	364	0.407	0.492
Internal R&D intensity	103	8.496	1.647	Competition degree	364	3.459	0.78
External R&D	364	0.232	0.423	Cooperation with clients	364	0.109	0.312
External R&D intensity	100	7.656	1.92	Cooperation with suppliers	364	0.121	0.326
Product innovation	364	0.448	0.498	Cooperation with competitors	364	0.088	0.284
Process innovation	364	0.324	0.469	Cooperation with public institutes	364	0.058	0.235
Organizational innovation	364	0.499	0.499	Cooperation with private institutes	364	0.088	0.283
Innovative performance	364	0.048	0.107	Cost-push	364	0.237	0.426
Labor Productivity	364	12.19	1.169	Demand-pull	364	0.421	0.494

Table 6: Estimation results for Software to manage orders

Regime 1	
Medium firm	-0.214
	(0.474)
Large firm	-0.894***
	(0.543)
Services sector	0.518
	(0.505)
Constant	-0.89
	(0.956)
Regime 2	
Size: 50-249	0.699**
	(0.338)
Size: $>$ 249	1.648**
	(0.713)
Services sector	-0.372
	(0.589)
Intranet usage in the sector in t-1	0.368
	(1.460)
Extranet usage in the sector in t-1	-3.685**
	(1.679)
Video-conference usage in the sector in t-1	2.106
	(2.042)
Electronic forum usage in the sector in t-1	-4.406**
	(1.956)
Electronic group calendar usage in the sector in t-1	2.399*
	(1.234)
Group project usage in the sector in t-1	-0.464
	(1.321)
DSL usage in the sector in t-1	2.805**
	(1.330)
Knowledge of the label Luxembourg in the sector in t-1	6.571***
	(2.215)
Knowledge of the Law code for e-commerce in the sector in t-1	-5.316
	(3.552)
Knowledge of the Law for electronic signature in the sector in t-1	3.366*
	(1.936)
Knowledge of the e-commerce committee in the sector in t-1	-3.590**
	(1.418)
Knowledge of the National Certification Office in the sector in t-1	1.704
	(2.192)
Software usage in the town in t-1	0.412
	(0.294)
Constant	-2.616*
	(1.386)
# obs.	364
Log pseudo likelihood	-465.2377
Wald chi2 (16)	26.13**

Note: * significant at 10%; ** significant at 5%;*** significant at 1%.
Robust standard errors in parentheses.

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