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ICT Use and Firm Innovation

An Empirical Analysis Based on Swedish Firm-Level Data

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Abstract

This study aims at investigating whether ICT use enables firm innovation. Moreover, it aims at ascertaining whether ICT use determines firms' degree of innovativeness and cooperation with different types of partners such as customers, suppliers and research institutions. Based on detailed Swedish firm-level data provided by *Statistics Sweden* that combines the innovation survey from 2012 with the survey of firms' ICT usage from 2010, a binary probit model has been applied for the empirical analysis. The results suggest that ICT use has a positive and significant effect on firm innovation. This is in accordance with previous studies within this field. Firms' ICT usage does however not have a significant effect on the most innovative firms, whereas it has a positive and significant effect on less innovative firms, which suggests that ICT usage primarily determines whether firms are innovative and not their degree of innovativeness.

Keywords: Innovation, ICT

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Table of Contents

1. Introduction 5
2. Definitions 7
2.1 Innovation 7
2.2 ICT Use 8
3. Previous Studies 9
3.2 Theoretical Predictions 9
3.2 Empirical Research 10
3.2.1 ICT and Productivity 10
3.2.2 ICT and Innovation 10
4. Methodology 14
4.1 Binary Choice Models 14
4.1.1 Marginal Effects 16
4.1.2 Estimation 16
4.1.3 Goodness-of-fit 17
4.2 Model Specification 18
5. Data 19
5.1 Dataset 19
5.2 Variable Description 20
5.2.1 Innovation Output 20
5.2.2 Cooperation 21
5.2.3 ICT Use 22
5.2.4 Control Variables 23
5.3 Summary Statistics 25
6. Results 27
6.1 ICT Use and Firm Innovation 27
6.2 ICT Use and Firm Cooperation 29
6.3 ICT Use and the Degree of Firm Innovativeness 31
6.3.1 True Innovators 31
6.3.2 Market Developers 33
6.3.3 Firm Developers 34
6.3.4 Non-innovative Firms 34
6.4 Robustness Checks 35
7. Conclusion 36
8. References 37
Appendix 40

List of Tables

Table 1. Categorisation of Firms Depending on their Innovativeness 21
Table 2. Correlations Between Different ICT Activities and the Innovation Groups 23
Table 3. Description of Control Variables 24
Table 4. Summary Statistics 25
Table 5. Results on ICT Use and Firm Innovation 27
Table 6. Results on ICT Use and Cooperation 30
Table 7. Results on ICT Use and Firm Innovativeness 32

1. Introduction

Firm innovation is essential for increased productivity and economic growth. At the firm level, innovations can potentially improve the quality of goods or services, and hence simultaneously increase consumer demand and decrease production costs (see for example Crépon, et al., 1998; Griffith et al., 2006; Parisi, et al. 2006). Firm innovation may also increase multifactor productivity, and consequently raise a nation's international competitiveness, economic growth and real per capita income (see for example Van Leeuwen & Klomp, 2006). The notion that innovation and economic performance is closely linked is widespread in the research literature (see for example Aghion, 2006; Botazzi, 2004; Sapir, 2004), but what determines whether a firm is innovative?

The use of information and communication technologies (ICT) has increased rapidly in OECD countries during the last two decades (OECD, 2014). With the potential of reducing transaction costs, improve business processes, facilitate coordination with various actors and disseminate information ICT involves substantial efficiency gains which in turn encourage innovation (Koellinger, 2005). Moreover, ICT could be seen as a general purpose technology that makes it relatively easy and cheap to innovate (Gretton et al., 2004).

While previous studies mainly have focused on ICT in relation to productivity (for a literature review see for example Cardona et al., 2013), the direct link between ICT and innovation has gained substantially less attention in the research literature. A few recent studies based on European firm-level data suggest that ICT use has a positive and significant impact on firm innovation (see for example Spiezia, 2011; Aoun & Dubrochard, 2012; Rybalka, 2012), but there are yet no study focusing solely on Swedish firms. This study aims to ascertain whether ICT use enable firm innovation in a Swedish setting. The main contribution of this paper is the application of a broader measure of ICT use and a dataset that combines the innovation survey from 2012 with the survey of firms' ICT usage from 2010, which renders problems of endogenous regressors and enables a discussion of causality.

Using the definition provided by the *Oslo Manual* an innovation refers to the implementation of a new or considerably improved product, process, marketing or organisational method (OECD & Eurostat, 2005). Focusing on innovation output, firms have been categorised as *true innovators, market developers, firm developers* and *non-innovative firms* depending on their innovativeness. Information and communications technology (ICT), on the other hand, is a broad concept that includes IT (hardware/software), data communication (internet/broadband) as well as telecommunication (mobile) (Cardona et al., 2013). Focusing on the first two subcategories, IT and data communication, this study applies a composite indicator of firm's ICT use that relates to the following three areas: automated systems that disseminate information within the firm after orders and purchases, as well as web sales.

Based on a sample of 1548 Swedish firms, this study aims at investigate whether ICT use enables firm innovation. The research question is specified as follows: *Does ICT use increase the probability of a firm being innovative?* Since the use of ICT not only may affect whether a firm is innovative, but how innovative a certain firm is, complementary estimations will be based on the following question: *Does ICT use increase the probability of being part of a certain group of innovative firms (referring to true innovators, market developers and firm developers)?*

A binary probit model is applied for the empirical analysis and the results suggest that ICT use enables firm innovation. Firms' ICT usage does however not have a significant effect on the most innovative firms, whereas it has a positive and significant effect on less innovative firms, which suggests that ICT usage primarily determines whether firms are innovative and not their degree of innovativeness.

The outline of the paper is as follows: Chapter 2 describes the main concepts of the paper. Chapter 3 accounts for theoretical as well as empirical previous studies in order to put this study in a wider context. Chapter 4 describes and motivates the methodological choice where after chapter 5 provides a more detailed description of the data before turning to the main findings of the paper presented in chapter 6. Lastly, chapter 7 summarises this study and makes suggestions for future research.

2. Definitions

This chapter provides definitions of the main concepts of the paper. A more detailed description of the different variables and how they have been constructed will be presented in chapter 5.

2.1 Innovation

An innovation not only refers to the implementation of a new or considerably improved product or process, but also includes new marketing or organisational methods. Based on the *Oslo Manual* there are four different types of innovation, namely *product innovations, process innovations, marketing innovations* and *organisational innovations* (OECD & Eurostat, 2005).

Based on a more detailed description of the different innovation types provided by Aoun and Dubrocard (2012, p. 318), product innovations refer to “significantly improved technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics” of a product or service. Process innovations involve “considerable changes in techniques, equipment and/or software”. Moreover, market innovations could be described in terms of “substantial changes in product design or packaging, product placement, product promoting or pricing” whereas organisational innovations refer to “the implementation of a new organisational method in the firm’s business practice, workplace organisation or external relations”.

In order to investigate whether ICT use affects the innovativeness of firms, firms have been divided into four different groups depending on how innovative they are, or in other words, how successful they have been in their development work. Firms have thus been categorised as *true innovators*, *market developers*, *firm developers* or *non-innovative firms*. A firm that has introduced a product that is new to the world market refers to a true innovator. A market developer, on the other hand, has presented a product that is new to the market in which the firm operates (the Swedish or the European market), but not to the world market. This category also includes firms that have developed processes that are new to the market. Moreover, a firm developer has developed a product or process that is new to the individual firm. Lastly, non-innovative firms have not managed to introduce a new product, process, marketing or organisational method during the two-year period covered by the innovation survey. Of course this does not mean that the non-innovative firms have not conducted any development work during this period, only that their innovation activities have not paid off yet. To clarify, innovation will throughout this paper refer to innovation output, that is, the outcome of firms' innovation activities.

2.2 ICT Use

Information and communications technology (ICT) is a broad concept that includes IT (hardware/software), data communication (internet/broadband) as well as telecommunication (mobile). Cardona et al. (2013, p.109) moreover describe ICT as "a special case of new technologies that serve as enabling technologies leading to even further innovations", which is what this study aims at investigate.

In the earlier literature ICT use has been measured in terms of computer use. This measure is irrelevant as of today when nearly all firms in advanced countries use computers (Rybalka, 2012). More recent studies (such as Abello & Prichard, 2008) have applied various measures of ICT use such as IT skills, broadband connections, web presence and ordering via Internet. Following Hagén et al. (2007), this study applies a broad measure of firms' ICT use in order to account for the fact that ICT use is a complex process with intertwined links between a wide range of different activities. Focusing on the IT and data communication, the composite indicator of firms' ICT use relates to the following three areas: automated systems that disseminate information within the firm after orders and purchases, and web sales. A more detailed description of the ICT variable will be presented in chapter 5.

3. Previous Studies

This chapter will initially account for some of the channels through which ICT use may enable firm innovation, thus providing a brief theoretical background before turning to the empirical results of earlier research.

3.2 Theoretical Predictions

According to Koellinger (2005) ICT use involves substantial efficiency gains, which in turn facilitate innovation. Efficiency gains from ICT use could for example be achieved through (1) reduced transaction costs, (2) improved business processes, (3) facilitated coordination with suppliers, fragmented processes along the value chain, and across different geographical locations as well as (4) increased diversification.

Additionally, Gretton et al. (2004) present the following two reasons why ICT use may encourage innovation. First of all, ICT can be seen as a general-purpose technology[1], which makes it relatively easy and cheap for firms to innovate. A firm that establishes a web presence does for example open up for various process innovations related to the ordering and delivery of products that due to the firm's web presence henceforth could be handled electronically. Secondly, ICT use may give rise to spill-over effects such as network economies that could function as important sources of productivity gains. Using an example provided by Spiezia (2011) the adoption of broadband enable firms to cooperate more closely and with a wider network of academics as well as international researchers on the progress of innovations, thus making it easier to keep up with current consumer trends.

[1] "a term coined to describe a new method of producing and inventing that is important enough to have a protracted aggregate impact" (Jovanovic, 2005 p.1182).

3.2 Empirical Research

Turning to the empirical research, studies on the relationship between ICT and productivity will be presented briefly before turning to studies on the relationship between ICT and innovation. This study aims at investigating the latter relationship, which constitute a substantially less researched field than the former.

3.2.1 ICT and Productivity

The effect of ICT on productivity has been examined by several empirical studies, and the vast majority confirm a positive and significant relationship (for a literature review see for example Cardona et al., 2013). Early studies within this field of research did however fail to identify and measure the impact of ICT on productivity (for a literature review see for example Brynjolfsson & Yang, 1996). Substantial ICT investments did not seem to have an impact on productivity growth, and referring to the *Solow paradox*, the computer age could be seen anywhere but in the productivity statistics (Solow, 1987). As researchers eventually turned to mico data in order to evaluate issues of measurement and identification, they found ICT to have a positive and significant effect on productivity. One of the first attempts to estimate the effect of ICT on productivity based on firm-level data was made by Brynjolfsson and Hitt (1995) where after a large empirical literature has emerged primarily making use of a production function framework (for more recent studies see for example Atrostic & Nguyen, 2002; Biscourp et al., 2002; Bresnahan et al., 2002; Brynjolfsson & Hitt, 2003; Crepsi et al., 2007; and OECD, 2004).

3.2.2 ICT and Innovation

Turning to the relationship between ICT and innovation, which has gained substantially less attention in the research literature, most previous econometric studies suggest that ICT facilitate firm innovation. The studies differ in terms of methodology, country coverage and whether or not they explicitly investigate the direct effect between ICT and firm innovation.

One strand of research includes ICT as an innovation input in a production function framework. CDM models (developed by Crépon et al., 1998) that distinguish between innovation input (R&D) and innovation output (knowledge) in order to detangle what drives productivity growth are often applied for this kind of analysis. Based on a sample of firm-level data for the Netherlands between 2002 and 2006, Van Leeuwen (2008) find ICT, measured in terms of e-sales and broadband use respectively, to have a significant effect on firm productivity through its effect on innovation output. While the result for e-sales is fairly robust, broadband does only have a significant effect on productivity when research and development (R&D) is not controlled for. Building on their analysis Polder et al. (2009 and 2010) conduct several analyses and consistently conclude that ICT is positively and significantly related to all types of service innovations. Turning to the results for the manufacturing sector, ICT is only found to have a limited effect on organisational innovations. While the empirical studies mentioned above deals with ICT and innovation, the direct link between the two is not investigated explicitly. Since the direct link between ICT and innovation is of main interest for this study the following paragraphs will account for previous studies that also have taken an interest in this matter.

Based on the Madrid Survey on Service Innovation, Gago and Rubalcaba (2007) apply an ordered probit model with sample selection in order to investigate the correlation between ICT investments and service innovations. Their results suggest that firms investing in ICT are significantly more likely to engage in service innovation, and the effect is particularly strong for firms that consider their investment to be very important or strategically important. While their study is based on a single statistical source and focus on ICT investments rather than the use of ICT, more recent studies have combined different statistical sources and applied different measures of ICT use, which has provided valuable insight on the relationship between ICT and innovation.

Abello and Prichard (2008) apply different logistic regressions on Australian firm-level data (obtained from the innovation survey and survey of firms ICT use) in order to investigate the relation between firms' ICT use and innovation. Their results indicate that there is a positive and significant relation between innovative firms and various measures of ICT use such as IT skills, broadband connection, web presence, and ordering via Internet. Moreover, their findings suggest that different ICT technologies relate to different types of innovation. Product innovations are for example associated with Internet connections via cable modem whereas wireless connections appear to have a significant effect on organisational innovations.

Spiezia (2011) investigate whether ICT use enables innovation using a probit model that allows for endogenous explanatory variables based on firm-level data for eight OECD-countries. The potential endogeneity of the ICT variable that may arise because of unobserved firm characteristics is solved by applying an instrument variable approach using lagged ICT as an instrument. The results confirm the hypothesis that ICT facilitate innovation, and are particularly strong for product and market innovations. In contrast to earlier studies Spiezia's findings suggest that ICT use has a highly significant effect on innovation not only for the service sector, but for the manufacturing sector as well. Spiezia could however not verify that ICT use is correlated with increased cooperation with other firms and/or institutions.

Building on Spiezia's work Rybalka (2012) examines what impact ICT has on the likelihood of firm innovation based on a rich dataset of Norwegian firms between 2002 and 2008. Rybalka applies a logistic model for the empirical analysis, and the obtained results confirm that ICT use has a positive effect on firms' innovation output. The effect is particularly strong for marketing and organisational innovations, and for the service sector. In accordance with Spiezia's findings, Rybalka cannot confirm a positive correlation between firms' ICT usage and their cooperation with other firms and/or institutions. Moreover, ICT use does not appear to increase the probability of presenting a product that is new to the market, which suggests that ICT use enable the adoption of innovations rather than the development of truly new products.

Another recent study conducted by Aoun and Dubrocard (2012) investigate the relationship between ICT and innovation based on a sample of Luxembourgian firms between 2004 and 2006. Their results suggest that there is a positive and significant correlation between ICT use, measured as the number of automatic links, and innovation for firms that have introduced product and process innovations. One should however be a bit careful when interpreting their results since the innovation survey has been combined with the ICT survey from the very same year, which causes problems of endogeneity. Alternative estimations have been conducted based on the same methodology as Spiezia and Rybalka allowing for endogenous regressors, but since these estimations according to the authors of the article did not improve upon the simpler probit model their results are based on the simpler model.

Another line of literature examines what role ICT has on organisational innovation alone (for a literature review see for example Brynjolfsson & Hitt, 2000). Case studies suggest that the introduction of ICT, investments in intangible assets as well as the transformation of firms including their relation with suppliers and customers occur simultaneously. Moreover, econometric studies based on firm level data indicate that the combination of ICT investments and organisational change has a positive impact on firm’s productivity growth (see for example Crespi et al., 2007).

Having accounted for previous studies that relates to ICT and innovation in some sense, the contribution of this study is to ascertain whether ICT use has an impact on firm innovation in a Swedish setting. Moreover, this study combines data on ICT use and innovation from different years, which circumvent the potential problem of applying a bad instrument that not only affect the dependent variable through its effect on the endogenous variable. Additionally, this study applies a broader ICT measure in contrast to previous studies that have applied various ICT measures. This broader measure is thought to better capture firm’s general level of ICT usage since different firms may apply different ICT activities depending on the development of their work.

4. Methodology

This chapter describes and motivates the choice of using the probit model for the empirical analysis. Moreover, the model specification is presented before turning to the results in the following chapter. Verbeek (2012) will be the main source of this chapter.

4.1 Binary Choice Models

Innovation is a binary dependent variable that equals one if a firm has introduced an innovation between 2010 and 2012 that is at least new to the individual firm, and zero otherwise. Applying a linear regression model is inappropriate in this case since the explanatory variables and their corresponding beta-coefficient, which are interpreted as probabilities, are not restricted to values between zero and one. A linear regression model could thus produce probabilities that exceeds one or goes below zero, which should not be a possibility. Moreover, the error term of a linear regression model has two possible outcomes in accordance with the dependent variable. The distribution of the error term is consequently highly non-normal and depends on both the explanatory variables and their beta-coefficients, which points to the presence of heteroskedasticity. In order to overcome these problems, a binary choice model (also known as a univariate dichotomous model) will be used for the empirical analysis.

More formally, a binary choice model could be described in terms of an underlying latent model

$$y_i^* = x_i'\beta + \varepsilon_i, \tag{1}$$

where y_i^* is an unobserved (latent) variable, which is a linear function of observed (x_i) and unobserved (ε_i) factors. Based on the assumption that a firm is innovative if it reaches a certain threshold, which has been set to zero, we observe the following two outcomes of the dependent variable

$$y_i = 1 \text{ if } y_i^* > 0$$

$$y_i = 0 \text{ if } y_i^* \leq 0. \tag{2}$$

Using a probit model, the unobserved factors (ε_i) follow a normal distribution with mean zero and variance one. The choice between different binary choice model will be discussed in more detail in the following paragraphs.

A binary choice model aims at describing the probability that $y_i = 1$ given a vector of explanatory variables, where firms' ICT usage is the explanatory variable of main interest for this study. In order to restrict the probabilities to only take values between zero and one, one could make use of some function *G*(.). This function could be thought of as a link function since it links the linear relationship between the dependent variable and the vector of explanatory variables to a function that only takes values between zero and one, as can be seen from the following expression

$$P\{y_i = 1|x_i\} = G(x_i, \beta). \tag{3}$$

One usually restricts the function *G*(.) to functions of the following form $G(x_i, \beta) = F(x_i'\beta)$, and since *F*(.) should lie in an interval between zero and one a natural choice would be choose *F* to be some distribution function. The standard normal distribution function is a common choice

$$F(x_i'\beta) = \Phi(x_i'\beta) = \int_{-\infty}^{w} \frac{1}{\sqrt{2\pi}} \exp\left\{-\frac{1}{2}t^2\right\} dt, \tag{4}$$

that results in the *probit model*. Another common choice is the logistic distribution function, which gives rise to the *logit model*. A third, but less common choice is the *linear probability model* that basically limit probabilities that exceeds one or goes below zero to one and zero, respectively. The probit model has a variance of one whereas the variance of the logit model equals $\pi^2/3$, which gives the latter model slightly fatter tails. Nevertheless, in general the two models yield very similar results after correct for the difference in scaling. The underlying distribution of the data at hand for this study is unknown, but since normality appears to be a reasonable assumption the probit model is applied for the empirical analysis. Additionally, most previous studies within this field of research have applied the probit model (see for example Spiezia, 2011).

4.1.1 Marginal Effects

The interpretation of the beta-coefficients obtained from a binary choice model are, except for the sign of the coefficient, not as straight forward as in the case of a linear regression model. To see why, consider the marginal effect of a change in one of the explanatory variables, which is defined as the partial derivative of the probability that y_i equals one,

$$\frac{\partial \Phi(x_i'\beta)}{\partial x_{ik}} = \phi(x_i'\beta)\beta_k, \qquad (5)$$

where $\phi(.)$ refers to the standard normal density function. Since the probit model is non-linear, the effect of a small change in x_{ik} varies with the size of x_i and β. In empirical work, marginal effects are therefore usually computed for the 'average' observation, which can be obtained by replacing x_i with the sample average in equation (5) above. For a discussion on the difference between the average marginal effect and the marginal effect at the average, as well as how to calculate standard errors for marginal effects see for example Greene (2012, Section 17.3).

4.1.2 Estimation

Applying a linear estimator to estimate the parameters of the probit model would be inappropriate because of the non-linear nature of the model. The most common choice for probit models (as well as logit models) is the maximum likelihood estimator, which consequently will be used for the estimations. The maximum likelihood principle rests on the assumption that the (conditional) distribution of the data is known. From this distribution the likelihood of observing the actual sample is determined as a function of the unknown parameters that characterises the standard normal distribution. Consequently, the values of the unknown parameters that maximized the likelihood of observing the actual sample are chosen as the maximum likelihood estimators. In case of a probit model the distribution is standard normal with mean zero and variance one.

Turning to the form of the likelihood function, the likelihood contribution of an innovative firm is given by $P\{y_i = 1|x_i\}$, which in turn is a function of the unknown parameter β, and similarly for a non-innovative firm. The likelihood function for the entire sample is thus given by

$$L(\beta) = \prod_{i=1}^{N} P\{y_i = 1|x_i;\ \beta\}^{y_i} P\{y_i = 0|x_i;\ \beta\}^{1-y_i}, \qquad (6)$$

which is the product of the likelihood functions of each innovative firm raised to the power of y_i (i.e. the number of innovative firms), and the likelihood function of each non-innovative firm raised to the power of $1 - y_i$ (i.e. the number of non-innovative firms). Taking logs and substituting $P\{y_i = 1|x_i;\ \beta\}$ with $F(x_i'\beta)$, one obtain the following expression

$$\log L(\beta) = \sum_{i=1}^{N} y_i \log F(x_i'\beta) + \sum_{i=1}^{N} (1 - y_i) \log(1 - F(x_i'\beta)), \qquad (7)$$

which is considerably easier to work with than the exponential equation specified in equation (6).

Differentiating equation (7) with respect to β results in the following expression

$$\frac{\partial \log L(\beta)}{\partial \beta} = \sum_{i=1}^{N} \left[\frac{y_i - F(x_i'\beta)}{F(x_i'\beta)(1 - F(x_i'\beta))} f(x_i'\beta) \right] x_i = 0, \qquad (8)$$

where f refers to the density function, which is the derivative of the distribution function. Since the probit model is applied for the empirical estimations, the distribution function in the above equations should of course be replaced by the standard normal distribution specified in equation (4). Lastly, the solution of equation (8) yields the maximum likelihood estimator $\hat{\beta}$ that consequently can be used to calculate the average marginal effect based on equation (5) since it is difficult to interpret the beta-coefficients directly other than the sign of the coefficients.

4.1.3 Goodness-of-fit

In contrast to a linear regression model, there is no single goodness-of-fit measure for binary choice models, but several measures indicating how well the model fits the data at hand. Generally, these measures are either computed from the likelihood function or based on a comparison of the correct and incorrect predictions of the model. For a general discussion of goodness-of-fit measures for non-linear models see for example Cameron & Trivedi (2005, Section 8.7).

4.2 Model Specification

Turning to the model specification, the following equation will be used for the empirical analysis:

$$y_i^* = \beta_{0i} + \beta_{1i} ICT\ use_i + \beta_2 X_i + u_i, \qquad (9)$$

where y_i^* denotes firm innovation output, $ICT\ use_i$ the level of firm ICT usage, which is the explanatory variable of main interest. Moreover, X_i refers to a vector of controls, which will be explained further in chapter 5 and u_i denotes the error term.

5. Data

Before turning to the empirical analysis, this chapter presents a more detailed description of the data and the variables that will be used for the estimations.

5.1 Dataset

The analysis is based on data from two statistical sources, namely the Community Innovation Survey (CIS) and the survey of ICT usage in firms conducted by *Statistics Sweden*. The innovation survey is carried out every other year whereas the ICT survey is conducted yearly. Combining the innovation survey from 2012 with the ICT survey from 2010 at the firm level yields 1548 mutual observations.

Since the innovation survey covers a period of two years, 2010-2012, ICT data for 2010 represents firms' ICT usage at the beginning of the period covered by the innovation survey. Consequently this enables a discussion of causality rather than simple correlation between firm's ICT usage and innovation output. Firm's initial level of ICT use may affect whether a firm manage to be innovative during the following two years whereas innovation output during the sample period should not have an effect on the initial level of firm's ICT use. Moreover, ICT data for 2012 is used as a robustness check even though one simply cannot say anything about causality in this case.

While the ICT survey contains firms of various sizes, the innovation survey is limited to firms with ten or more employees, thus creating a sample that is biased towards larger firms. This may be problematic since a majority of Swedish firms have less than ten employees (SCB, 2015). However, since larger firms tend to be more innovative a bias towards larger firms is perhaps not too worrisome.

In order to be able to say something about Swedish firms in general and not only the firms that have complied with the innovation and ICT survey, all observations have been assigned a weight. The weight relates the total number of firms (N) to the number of sampled firms (n) within each stratum by dividing the former with the latter (N/n). If for example 10 out of 100 existing firms within a certain stratum answer both surveys, each of these sampled firms are assigned a weight of 10 (100/10) in order to account for the total number of firms within this stratum.

5.2 Variable Description

This section accounts for a more detailed description of the different variables that will be used for the empirical analysis.

5.2.1 Innovation Output

As mentioned in chapter 2, firms have been categorised into four different groups depending on how innovative they are, namely *true innovators*, *market developers*, *firm developers* and *non-innovative firms*. The first three groups of firms, *true innovators*, *market developers*, and *firm developers*, are innovative in some sense and thus form the more aggregated group of *innovators* that we are primarily interested in. The variable *innovators* is binary and equals one if a firm has been innovative during the sample period and zero otherwise. In order to investigate whether ICT use determines the degree of firm innovativeness, complementary estimations will apply the four different groups of firms as binary dependent variables. Each group of firms form a binary variable, which equals one if the criterion for being part of a certain group is fulfilled and zero otherwise. *Table 1* shows the share of firms belonging to the different groups.

Table 1. Categorisation of Firms Depending on their Innovativeness

Group of Firms	(%)
Innovators	39.2
True innovators	6.0
Market developers	8.5
Firm developers	24.7
Non-innovative firms	60.8

(The group of *innovators* is the sum of *true innovators*, *market developers* and *firm developers*, which explains why the percentages presented in the table exceed 100 percent).

As can be seen from the table, most firms belong to the group of non-innovative firms. Out of the firms that have been innovative, the group of firm developers is the largest, and constitute almost one fourth of the total number of firms. The share of firms that belong to the group of market developers and true innovators are considerably smaller, only accounting for approximately nine and sex percent respectively.

Worth mentioning is that the different innovation types presented in chapter 2, *product innovations*, *process innovations*, *marketing innovations* and *organisational innovations*, are associated with differently detailed data. Data is most detailed for product innovations, followed by process innovations, and are thus least detailed for marketing and organisational innovations. Regarding marketing and organisational innovations one can for example only tell whether or not a firm's development work has resulted in an innovation between 2010 and 2012, whereas the innovation survey holds information on whether or not a process innovation is new to the market or the individual firm. Moreover, data on product innovations enable a categorisation into all different groups of firms mentioned above.

5.2.2 Cooperation

Since ICT usage may affect firm innovativeness through increased cooperation with various partners, a complementary estimation will examine the relationship between ICT use and firm cooperation. The innovation survey entails detailed information on what type of organisations a certain firm has undertaken development projects with. Based on the following categories a dummy variable has been created that equals one if a firm cooperates with at least one of the organisations in their development work: *corporate group*, *suppliers*, *customers* (private or public sector), *competitors*, *consultants*, *universities*, and *research institutions* (private or public).

5.2.3 ICT Use

According to Hagén et al. (2007) ICT use is a complex process with intertwined links between a wide range of different activities. If firms' ICT use were to be represented by a single activity and turned out to be significant in a regression framework, the result would most probably be exaggerated. Since the different activities are often closely linked, and a certain firm probably use ICT in more than one way, the regression results would capture the effect of all these different activities rather than the effect of the single ICT activity included in the regression model. This study thus applies a broader measure of firms' ICT use, which is a composite indicator that captures three different areas of ICT activities, namely automated systems that disseminate information within the firm after orders and when purchasing, as well as (the occurrence of) web sales. Each of these activities relates to between one and three yes-no questions in the ICT survey. The subcategories these questions compose are summed within each area of ICT activities, which in turn are aggregated into a composite indicator representing the ICT usage of a firm. See *Table 2* below for an overview. Moreover, all partial measures and their aggregates have been standardised and can vary between zero and one, thus making a comparative analysis between the different ICT activities meaningful. Depending on how many different ICT activities a certain firm undertake the composite indicator ICT use stretches from 1 to 6, where 1 refers to a low ICT usage and 6 to a high ICT usage.

Table 2. Correlations Between Different ICT Activities and the Innovation Groups

ICT activity	True innovator	Market developer	Firm developer	Non-innovative firm
Information shared after customer order	0.123***	0.084**	0.177***	-0.264***
Control of inventory levels	0.100***	0.046	0.123***	-0.184***
Accounting	0.105***	0.065*	0.155***	-0.226***
Production or service management	0.104***	0.100***	0.167***	-0.256***
Information shared when purchasing	0.093***	0.050*	0.149***	-0.206***
Control of inventory levels	0.073**	0.017	0.130***	-0.160***
Accounting	0.092***	0.072**	0.137***	-0.207***
Web sales	0.040	0.032	0.122***	-0.145***
ICT use	0.117***	0.075**	0.187***	-0.264***

(*<p=0.5, **<p=0.1, ***<p=0.01).

As can be seen from *Table 2*, the composite indicator ICT use is positively correlated with firm innovation. Out of the innovative firms, the correlation is strongest for firm developers, followed by true innovators, and least significant for the group of market developers. ICT activities related to information shared within the firm both after customer order and when purchasing (and a majority of its subcategories) are positively correlated with firm innovation, whereas the positive correlation between web sales and innovation only turned out to be significant for firm developer. Turning to the non-innovative firms, all ICT activities are negatively correlated with this group of firms.

5.2.4 Control Variables

A vector of controls consisting of *firm size*, *membership in a corporate group*, the share of employees with a certain *educational level* and *educational field*, as well as *industry dummies* has been included to account for factors that may stimulate firm innovation. *Table 3* below presents a more detailed description of these variables.

Table 3. Description of Control Variables

Variable	***Description***
Firm size	Measures as the (logged) total number of employees.
Membership in a corporate group	Binary variable that equals one if a firm is member of a corporate group and zero otherwise.
Educational level	Educational level refers to the highest finished educational level of an employee. Based on seven educational levels (compulsory education, compulsory education 9 years, upper secondary, upper secondary 3 years, post-secondary, post-secondary 3 years, and research degree), the share of employees belonging to each educational level has been calculated on a firm basis. The first educational level (compulsory education) has been used as a base category in order to avoid problems of multicollinearity and dummy traps.
Educational field	The share of employees that have studied a technical or scientific subject has also been calculated for each firm. Notably, this variable only applies to employees that have finished an upper secondary 3 years or post-secondary education.
Industry dummies	Industry dummies have been included in the vector of controls in order to control for potential differences in ICT usage between the following sectors: capital intensive good, capital intensive manufacturing, labour intensive manufacturing, knowledge intensive manufacturing, trade, capital intensive service, knowledge intensive service, and finance. In this case, the knowledge intensive manufacturing sector has been used as a base category in order to avoid problems of multicollinearity and dummy traps.

Larger firms tend to engage in a wider range of different activities in comparison to firms of smaller size. Since a wider range of firm activities provides greater opportunities for innovation, firm size is expected to have a positive effect on firm innovation. Membership in a corporate group could substantially increase the network of a firm, especially if the firm is small. Membership in a corporate group thus relates to firm size since a smaller firm could enjoy benefits that normally are limited to firms of larger size through its membership in a corporate group. Variables capturing the share of employees with higher levels of education as well as a technical or scientific degree are also expected to have a positive effect on firm innovation because these factors are usually correlated with more advanced ICT usage. Lastly, industry dummies have been included in the vector of controls in order to account for the fact that some sectors may use ICT more intensively than others, which consequently could have a positive effect on their innovation capabilities. According to McGuckin and Stiroh (2001) ICT is for example used more intensively in the service sector.

5.3 Summary Statistics

Having described the data and the different variables, this section presents summary statistics before turning to the empirical analysis.

Table 4. Summary Statistics

Variable	**Mean**	**Std.Dev.**	**Min.**	**Max.**
Dependent variable				
Innovator	0.392	1.266	0	1
True innovator	0.060	0.616	0	1
Market developer	0.085	0.724	0	1
Firm developer	0.247	1.118	0	1
Non-innovative firm	0.608	1.266	0	1
Cooperation	0.144	0.909	0	1
Explanatory variable				
ICT use	1.918	5.370	1	6
Size	3.536	2.823	2.303	9.798
Corporate group	0.758	1.111	0	1
Educational level of employees				
Compulsory 9 years	0.120	0.271	0	0.565
Upper secondary school	0.250	0.382	0	0.750
Upper secondary 3 years	0.296	0.379	0	0.852
Post-secondary	0.145	0.292	0	0.667
Post-secondary 3 years	0.151	0.481	0	1
Research degree	0.010	0.139	0	0.583
Industry				
Technical and scientific	0.381	0.623	0	1
Capital intensive good	0.036	0.484	0	1
Capital int. manufacturing	0.042	0.517	0	1
Labour int. manufacturing	0.205	1.046	0	1
Trade	0.285	1.171	0	1
Capital intensive service	0.112	0.817	0	1
Knowledge intensive service	0.192	1.021	0	1
Finance	0.026	0.410	0	1

As can be seen from *Table 4* above a majority of the variables are binary, which means that their mean refers to the share of the observations that equals one. Consequently, there are about 39 percent innovative firms, distributed as approximately 6 percent true innovators, 9 percent market developers and 25 percent firm developers. A majority of the firms have however not introduced a product, process, marketing or organisational method that is at least new to the individual firm during the sample period. Additionally, only about 14 percent of the firms cooperate with organisations such as suppliers, customers and research institutions in their development work. Turning to the explanatory variable of main interest, ICT use, it is described on a scale from 1 to 6, where 1 refers to a low ICT usage and 6 to a high ICT usage. The mean is approximately 2, and the standard deviation of the variable is notably large exceeding 5.

6. Results

This chapter presents and analyses the main results of this paper. Evidence on the relationship between ICT use and firm innovation will be accounted for initially followed by results on the correlation between ICT use and cooperation. Thereafter, a further examination of whether ICT use determines the innovativeness of firms will follow. Lastly, the accuracy of the results is discussed based on various robustness checks.

6.1 ICT Use and Firm Innovation

This study aims at determining whether ICT use enables firm innovation, and the question of main interest is thus: *Does ICT use increase the probability of a firm being innovative?* The model has been estimated both with and without the vector of controls in order to ascertain that the inclusion of the control variables provides a better fit of the data. The results are presented in *Table 5* below and the estimation without the vector of controls is found in column 1 whereas the estimation with control variables are presented in column 2.

Table 5. Results on ICT Use and Firm Innovation

Explanatory variable	**(1) Innovator**	**(2) Innovator**
ICT use	**0.060****** (0.016)	**0.043****** (0.018)
Size		**0.044****** (0.035)
Corporate group		0.051 (0.093)
Compulsory 9 years		**-1.238****** (1.016)
Upper secondary school		-0.371 (0.910)
Upper secondary 3 years		-0.337 (0.861)
Post-secondary		-0.095 (0.936)
Post-secondary 3 years		-0.137 (0.884)
Research degree		0.167 (1.114)
Technical and scientific		**0.139*** (0.178)

Capital intensive good		**-0.229**** (0.213)
Capital intensive manufacturing		**-0.181**** (0.204)
Labour intensive manufacturing		-0.048 (0.136)
Trade		**-0.176***** (0.137)
Capital intensive service		**-0.260***** (0.173)
Knowledge intensive service		**-0.239***** (0.161)
Finance		-0.095 (0.256)
Constant	**-0.762***** (0.058)	0.124 (0.841)
R-square		
Adj.R-square		
Mc Fadden	*0.052*	*0.149*
Number of observations	*1548*	*1548*

(Standard errors in parentheses,*<p=0.5, **<p=0.1, ***<p=0.01. Significant results are bold, and average marginal effects are presented).

First of all, the larger McFadden value obtained for the model including the vector of controls suggests that this model fits the data better than the model without controls. Moreover, the model without control variables most likely overestimates the effect of the ICT variable since the size of the effect is substantially lower for the model including control variables. Based on this reasoning, the model presented in column 2 that includes the vector of controls will be used for the forthcoming analysis.

As can be seen from *Table 5* above, ICT use has a positive and highly significant effect on firm innovation. A one unit increase of ICT use increases the probability of a firm being innovative by 4.3 percent. The effect might seem small at a first glance, but each innovation could be of great importance not only for an individual firm, but for an entire sector, and consequently give rise to positive effects of considerable size. Moreover, based on the number of Swedish firms in 2012 being approximately 1,137,000, an increase of about 4 percent in the probability of being innovative would result in 45,500 more innovations (SCB, 2015). Based on this reasoning, ICT use indeed has a great impact on firm innovation. The finding that ICT use has a positive and significant impact on firm innovation is confirmed by previous studies based on European firm-level data (see for example Spiezia, 2011; Rybalka, 2012;

Aoun & Dubrocard, 2012). Comparing findings on the size of the effect is however much more difficult since different studies apply different measures of ICT use, which renders a direct comparison.

In addition to ICT use firm size also has a positive and highly significant effect on firm innovation. This is exactly what we would expect since a larger firm reasonably engage in a greater number of different activities, thus giving rise to more innovation opportunities. An increase of the number of employees by one percent is associated with a 4 percent increase in the probability of being innovative. Turning to the vector of controls, the share of employees with compulsory education (9 years) as the highest finished educational level has a negative impact on the probability of being innovative. The variables capturing the share of employees with higher educational levels are however not found to have a significant effect on firm innovation. Nevertheless, having studied a technical or scientific subject at either upper secondary (3 years) or post-upper secondary has a positive and significant effect on firm innovation. The size of the effect is 0.14. Regarding the industry specific effects, the following sectors are found to have a significantly negative impact on firm innovation: capital intensive good, capital intensive manufacturing, trade, capital intensive service and knowledge intensive service.

6.2 ICT Use and Firm Cooperation

Having accounted for the empirical evidence on the relationship between ICT use and firm innovation, this section examines whether ICT use relates to firm cooperation. This relationship is of interest since cooperation is one possible channel through which ICT use may affect innovation. The results are presented in *Table 6* below.

Table 6. Results on ICT Use and Cooperation

Explanatory variable	**Cooperation**
ICT use	**0.013*** (0.023)
Size	**0.051***** (0.041)
Corporate group	-0.026 (0.119)
Compulsory 9 years	-0.388 (1.483)
Upper secondary school	-0.117 (1.275)
Upper secondary 3 years	-0.121 (1.232)
Post-secondary	0.307 (1.318)
Post-secondary 3 years	0.168 (1.243)
Research degree	**1.340***** (1.557)
Technical and scientific	**0.178**** (0.222)
Capital intensive good	-0.029 (0.244)
Capital intensive manufacturing	-0.039 (0.243)
Labour intensive manufacturing	0.012 (0.161)
Trade	**-0.113**** (0.163)
Capital intensive service	-0.072 (0.215)
Knowledge intensive service	**-0.138**** (0.186)
Finance	-0.009 (0.294)
Constant	-1.964 (1.200)
R-square	
Adj.R-square	
Mc Fadden	*0.200*
Number of observations	*1548*

(Standard errors in parentheses,*<p=0.5, **<p=0.1, ***<p=0.01. Significant results are bold, and average marginal effects are presented).

As can be seen form the table, cooperation in development work with for example suppliers, customers and research institutions is found to have a positive and significant effect on ICT use. The size of the effect is very small. A one unit increase in ICT use relates to a one percent increase in the probability of firm cooperation. Out of eight sample countries, Spiezia (2011) only found a positive effect for the UK and the Netherlands, whereas Rybalkaba (2012) did not find a significant correlation between ICT use and firm cooperation for Norwegian firms, which suggest that the results presented above should be interpreted with caution.

6.3 ICT Use and the Degree of Firm Innovativeness

Having established a positive relationship between ICT usage and firm innovation this section further investigates whether ICT use may determine how innovative firms are. The different groups of innovative firms, namely *true innovators, market developers* and *firm developers* will thus be used as binary dependent variables for their respective model estimation. Notably, if one aims at ascertaining whether ICT usage determines firm innovativeness one should only compared a group of firms against firms that are less innovative. Since we are primarily interested in whether ICT use increases the probability of moving from one group to the following more innovative group, true innovators are compared against market developers, market developers against firm developers, and firm developers against non-innovative firms.

6.3.1 True Innovators

Starting with the most innovative group of firms, namely the true innovators that have presented a product that is new to the world market during the sample period, the results are presented in column 1 in *Table 7* below.

Table 7. Results on ICT Use and Firm Innovativeness

Explanatory variable	(1) True innovator	(2) Market developer	(3) Firm developer	(4) Non-innovative firm
ICT use	0.018 (0.039)	-0.004 (0.030)	**0.048**** (0.022)	**-0.043***** (0.018)
Size	-0.015 (0.065)	**0.049**** (0.053)	**0.027*** (0.042)	**-0.044***** (0.035)
Corporate group	**0.338***** (0.273)	-0.041 (0.164)	0.058 (0.108)	-0.051 (0.093)
Compulsory 9 years	0.673 (3.153)	**-0.915**** (1.838)	-0.709 (1.206)	**1.238***** (1.016)
Upper secondary school	0.725 (2.638)	**-1.258*** (1.550)	0.247 (1.103)	0.371 (0.910)
Upper secondary 3 years	0.286 (2.294)	**-1.399**** (1.482)	0.358 (1.062)	0.337 (0.861)
Post-secondary	0.926 (2.505)	-0.711 (1.565)	0.181 (1.128)	0.095 (0.936)
Post-secondary 3 years	1.037 (2.449)	-0.728 (1.506)	0.253 (1.075)	0.137 (0.884)
Research degree	-0.844 (2.862)	-0.521 (1.753)	0.702 (1.358)	-0.167 (1.114)
Technical and scientific	**0.508***** (0.410)	-0.093 (0.297)	0.072 (0.212)	**-0.139*** (0.178)
Capital intensive good	-0.389 (0.619)	-0.050 (0.359)	-0.168 (0.240)	**0.229**** (0.213)
Capital intensive manufacturing	-0.044 (0.338)	0.171 (0.325)	**-0.270**** (0.266)	**0.181**** (0.204)
Labour intensive manufacturing	**-0.182*** (0.270)	0.074 (0.195)	-0.051 (0.158)	0.048 (0.136)
Trade	-0.111 (0.260)	0.024 (0.212)	**-0.198***** (0.162)	**0.176***** (0.137)
Capital intensive service	**0.364*** (0.531)	-0.147 (0.372)	**-0.250***** (0.202)	**0.260***** (0.173)
Knowledge intensive service	-0.294 (0.311)	-0.112 (0.256)	**-0.169**** (0.189)	**0.239***** (0.161)
Finance	**-0.223**** (0.572)	-0.102 (0.380)	-0.045 (0.296)	0.095 (0.256)
Constant	-3.634 (2.330)	2.218 (1.393)	-1.562 (1.029)	-0.124 (0.841)
Mc Fadden	*0.177*	*0.069*	*0.127*	*0.149*
Number of observations	*330*	*620*	*1218*	*1548*

(Standard errors in parentheses,*<p=0.5, **<p=0.1, ***<p=0.01. Significant results are bold, and average marginal effects are presented for the binary probit model. In column 1 *true innovators* are compared against *market developers*, in column 2 *market developers* stand against *firm developers*, whereas column 3 compare *firm developers* against *non-innovative firms*).

As can be seen from the table, the number of observations is considerably lower in comparison to the other estimations. This results from the comparison only between true innovators and market developers, which account for a fairly small amount of the total number of firms. True innovators are not compared to all other firms since we are primarily interested in what distinguishes true innovators from market developers.

Turning to the results, ICT use is not found to have a significant effect on the probability of being a true innovator, whereas being part of a group and having employees with a technical or scientific degree has a positive and significant effect. Moreover, these two variables have a sizeable effect on the probability of being a true innovator. Being part of a corporate group is associated with an increase of 34 percent of being a true innovator, and the share of a firm's employees with a technical or scientific degree increases the probability of being classified as a true innovator with as much as 51 percent. Turning to the industry variables, the capital intensive service sector has a positive and significant effect on the probability of being a true innovator, whereas the labour intensive manufacturing sector and the finance sector appears to have a significantly negative effect.

The same result holds when comparing true innovators against both market developers and firm developers. When comparing the group of true innovators against all other firms (innovative as well as non-innovative), ICT use does however turn out to have a positive and significant effect on the probability of being a true innovator at the 5 percent level. A one unit increase in ICT use is associated with a 1.4 percent increase in the probability of being a true innovator.

6.3.2 Market Developers

Having accounted for the group of most innovative firms this section turns to the group of market developers. The second column of *Table 7* presents estimations on the relationship between market developers and firm developers. In accordance with the findings for the group of true innovators, ICT use is not found to have a significant effect on the probability of introducing a product or process that is new to the market in which the firm operates. Among the control variables firm size is found to have a positive and significant effect on the probability of being a firm developer, whereas variables such as the share of the employees having compulsory (9 years) education, upper secondary school or upper secondary 3 years as the highest level of education has a significantly negative effect on being a market developers. Additionally, a complementary estimation comparing the group of market developers against firm developers and non-innovative also suggests that ICT use has an insignificant effect on the probability of being a market developer confirming the results presented above.

6.3.3 Firm Developers

Lastly, the results for the least innovative group of firms, firm developers, will be presented and discussed in this section. As can be seen from column 3 in *Table 7* on page 32, ICT use is found to have a positive and significant effect on introducing any of the four innovation types during the sample period that is new to the individual firm. A one unit increase in ICT usage increases the probability of being a firm developer by almost 5 percent. The size of the effect is thus very similar to the one obtained for all groups of innovative firms in section 6.1, which also includes true innovators and market developers. Regarding the vector of controls, firm size has a positive and significant effect on the probability of being a firm developer. The following sectors are however significantly negatively related to the probability of being a firm developer: capital intensive manufacturing, trade, capital intensive service, and knowledge intensive service.

6.3.4 Non-innovative Firms

For completeness, the result for non-innovative firms is presented in column 4 of *Table 7*. This result will however not be discussed any further since the relationship between ICT use and firms that have been innovative during the sample period is of main interest for this study.

6.4 Robustness Checks

Various robustness checks have been applied to ascertain the reliability of the results presented in this chapter. First of all, a linear probability model has been used for the estimations since Angrist and Pischke (2008) argues that a binary and a linear probability model yield very similar results in empirical work. The results obtained using the linear probability model are in line with the estimations based on the binary probit model with one major difference. ICT use did not turn out to have a significant effect on the probability of firm cooperation, which further points to that this result should be interpreted with caution.

Additionally, the composite indicator of ICT use based on the survey conducted in 2012 has been used for the estimations as a robustness check. We are primarily interested in the sign and significance of the ICT variable, and not so much the size of the average marginal effects since ICT use data from 2012 most probably should be treated as an endogenous explanatory variable in accordance with estimations performed by Spiezia (2011) and Rybalkaba (2012). Nevertheless, the results based on ICT use data from 2012 can be found in appendix A, and we obtain similar results in terms of sign and significance for the ICT variable, which suggests that our findings are fairly robust. Lastly, unweighted observations have also been used for the various estimations, and the results do not change notably.

To sum up the main results presented in this chapter, the empirical evidence suggests that ICT use has a positive and significant effect on the probability of firm innovation. ICT use does however not have an effect on the probability of being neither a true innovator nor a market developer, which suggests that ICT rather effects whether a firm is innovative than the degree of innovativeness. The finding that ICT use is positively and significantly related to the probability of being a firm developer confirms this hypothesis and proposes that it is mainly this group of firms that drives the positive correlation between ICT use and firm innovation. Moreover, the results obtained appear to be fairly robust according to the various robustness checks performed.

7. Conclusion

This study examines whether ICT use stimulates firm innovation based on a sample of 1548 Swedish firms between 2010 and 2012 by applying a binary probit model. The results suggest a positive and highly significant effect between ICT usage and firm innovation, which confirms the findings of previous studies based on European firm-level data. The variable capturing ICT use is a composite indicator that stretches from 1 to 6, and according to the results a one unit increase of ICT use increases the probability of a firm being innovative with about 4 percent. At a first glance, the effect might seem small. Nevertheless, a single innovation could have a major impact on an individual firm or a sector, and given the existence of 1,137,000 Swedish firms in 2012 (SCB, 2015), a one unit increase of ICT use would result in 45,500 more innovations, which suggests that the effect is of considerable size.

Having established a positive and significant relationship between ICT use and firm innovation, this study further investigates whether ICT usage determines how innovative firms are. Firms have been categorised depending on their innovativeness, and the results suggest that ICT usage has an insignificant effect in the most innovative firms, true innovators and market developers. A positive and significant effect were however found for the less innovative group of firm developers, which suggests that ICT use rather determines whether firms are innovative than their degree of innovativeness. Moreover, ICT use were found to be positively correlated with firm cooperation with different organisations such as suppliers, consumers and research institutions, but since previous studies and the application of the linear probability model were unable to find a significant relation between the two, the results should be interpreted with caution.

For future research a further division of how ICT use relates to the different types of innovations (*product*, *process*, *marketing* and *organisational method*) could be of interest in a Swedish perspective. Moreover, since both the innovation survey and the survey of firms' ICT usage, which the dataset of this study builds on, are based on EU directives, this enables similar estimations based on data for other European countries.

8. References

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Appendix

A. Robustness Check using ICT use 2012

Table A1. Results on ICT Use and Firm Innovation

Explanatory variable	**(1) Innovator**	**(2) Innovator**
ICT use	**0.126***** (0.041)	**0.080***** (0.047)
Size		**0.055***** (0.031)
Corporate group		0.029 (0.073)
Compulsory 9 years		**-1.475***** (0.750)
Upper secondary school		**-1.118***** (0.679)
Upper secondary 3 years		**-0.897***** (0.633)
Post-secondary		**-0.560*** (0.676)
Post-secondary 3 years		**-0.698**** (0.661)
Research degree		0.654 (1.665)
Technical and scientific		**0.149**** (0.150)
Capital intensive good		**-0.232**** (0.240)
Capital intensive manufacturing		-0.082 (0.237)
Labour intensive manufacturing		-0.065 (0.135)
Trade		**-0.146**** (0.131)
Capital intensive service		**-0.170**** (0.152)
Knowledge intensive service		**-0.186***** (0.154)
Finance		-0.097 (0.225)
Constant	**-0.965***** (0.079)	**1.469***** (0.623)
R-square		
Adj.R-square		
Mc Fadden	*0.025*	*0.116*
Number of observations	*2094*	*2094*

(Standard errors in parentheses,*<p=0.5, **<p=0.1, ***<p=0.01. Significant results are bold, and average marginal effects are presented).

Table A2. Results on ICT Use and Cooperation

Explanatory variable	**Cooperation**
ICT use	**0.036*** (0.062)
Size	**0.051***** (0.035)
Corporate group	-0.023 (0.097)
Compulsory 9 years	-0.461 (1.070)
Upper secondary school	**-0.449*** (0.965)
Upper secondary 3 years	-0.373 (0.908)
Post-secondary	-0.083 (0.961)
Post-secondary 3 years	-0.220 (0.934)
Research degree	**1.442***** (1.787)
Technical and scientific	**0.159***** (0.197)
Capital intensive good	0.008 (0.255)
Capital intensive manufacturing	-0.007 (0.261)
Labour intensive manufacturing	-0.053 (0.160)
Trade	**-0.079*** (0.150)
Capital intensive service	**-0.139**** (0.200)
Knowledge intensive service	**-0.129**** (0.178)
Finance	-0.010 (0.257)
Constant	-0.796 (0.888)
R-square	
Adj.R-square	
Mc Fadden	*0.151*
Number of observations	*2094*

(Standard errors in parentheses,*<p=0.5, **<p=0.1, ***<p=0.01. Significant results are bold, and average marginal effects are presented).

Table A3. Results on ICT Use and Firm Innovativeness

Explanatory variable	**(1) True innovator**	**(2) Market developer**	**(3) Firm developer**	**(4) Non-innovative firm**
ICT use	-0.041 (0.115)	0.050 (0.082)	**0.066***** (0.053)	**-0.090***** (0.047)
Size	0.005 (0.056)	**0.039**** (0.045)	**0.040***** (0.036)	**-0.055***** (0.031)
Corporate group	**0.147*** (0.197)	**-0.962*** (0.132)	0.048 (0.084)	-0.029 (0.073)
Compulsory 9 years	0.961 (2.849)	**-1.038**** (1.303)	**-1.115***** (0.817)	**1.475***** (0.750)
Upper secondary school	-0.164 (2.380)	-0.408 (1.089)	**-0.897***** (0.746)	**1.118***** (0.679)
Upper secondary 3 years	0.406 (2.166)	-0.489 (0.970)	**-0.714**** (0.696)	**0.897***** (0.633)
Post-secondary	0.506 (2.293)	-0.166 (1.018)	-0.479 (0.740)	**0.560*** (0.676)
Post-secondary 3 years	0.380 (2.226)	0.078 (1.020)	**-0.713**** (0.728)	**0.698**** (0.661)
Research degree	**2.037*** (3.007)	-0.243 (2.022)	0.302 (1.843)	-0.654 (1.667)
Technical and scientific	**0.328**** (0.366)	**-0.217**** (0.253)	**0.169**** (0.171)	**-0.149**** (0.147)
Capital intensive good	**-0.343*** (0.523)	0.102 (0.366)	**-0.238*** (0.289)	**0.232**** (0.240)
Capital intensive manufacturing	-0.048 (0.350)	**0.227*** (0.353)	-0.174 (0.308)	0.082 (0.237)
Labour intensive manufacturing	**-0.244**** (0.280)	0.113 (0.206)	-0.072 (0.156)	0.065 (0.135)
Trade	-0.002 (0.246)	-0.095 (0.201)	**-0.121*** (0.152)	**0.146**** (0.131)
Capital intensive service	-0.180 (0.366)	-0.056 (0.247)	**-0.163**** (0.176)	**0.170**** (0.152)
Knowledge intensive service	**-0.239*** (0.289)	**-0.227**** (0.242)	-0.090 (0.179)	**0.186***** (0.154)
Finance	-0.190 (0.440)	-0.207 (0.330)	-0.003 (0.262)	0.097 (0.225)
Constant	-1.637 (2.130)	0.293 (0.936)	0.899 (0.686)	**-1.469*** (0.623)
Mc Fadden	*0.119*	*0.077*	*0.077*	*0.116*
Number of observations	*405*	*809*	*1689*	*2094*

(Standard errors in parentheses,*<p=0.5, **<p=0.1, ***<p=0.01. Significant results are bold, and average marginal effects are presented for the binary probit model. In column 1 *true innovators* are compared against *market developers*, in column 2 *market developers* stand against *firm developers*, whereas column 3 compare *firm developers* against *non-innovative firms*).