ICT, innovation and productivity: evidence from Latin American firms[1]

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This version: May 30th 2015

It is generally recognized that Information and Communication Technologies (ICTs) have radically changed how modern business is conducted, benefitting firm performances through several channels, such as increasing the efficiency of internal processes, expanding market reach or increasing innovation. However, most related literature refers to developed countries and evidence for Latin America is scarce and fragmented. This paper contributes to fill in this gap by identifying the drivers of ICT diffusion in LAC firms and assessing the relationship between ICTs and firm performance in the region. We find evidence of the presence of both epidemic and rank effects, where larger, older, skill-intensive, exporter and urban firms are more likely to adopt ICTs. However, once adopted, size and location lose importance. Additionally, our results show a positive relationship between broadband and firm-performance. In particular, firms that have adopted broadband increase the probability of innovating, and this effect is found to be mainly related to the use of broadband to perform research and development activities. Moreover, the combined use for different activities is found to have an additional positive effect on firm innovation performance. Further estimations also provide evidence on the fact that broadband adoption and use constitute a source of productivity growth for Latin American firms.

Keywords: ICT, Technology Diffusion, Innovation, Productivity, Latin America
JEL Classification: D22, O31, O33, O54

[1] The contents are sole responsibilities of the authors, and do not necessarily reflect the position of the Inter-American Development Bank. We thank Carlos Pietrobelli, Eddy Szirmai and Sebastián Vergara for very helpful comments and discussion. Siobhan Pangerl and Leonardo Ortega provided excellent research assistance.

1. Introduction

Over the last decades, the economic literature has progressively recognized the role of Information and Communication Technologies (ICTs) as a key driver of economic growth. In particular, a large body of research has clearly shown the link between the acceleration of productivity growth and ICT diffusion in the context of growth accounting (Oliner and Sichel, 1994 and 2002; Jorgenson, 2001).

At the firm level, ICT adoption can improve business performance through various channels. ICTs allow faster communication and quicker processing of information, decreasing internal coordination costs, and facilitate the decision making processes (Cardona, Kretschmer, and Strobel, 2013; Arvanitis and Loukis, 2009; Atrostic et al., 2004; Gilchrist, Gurbaxani, and Town, 2001). ICTs may also promote substantial firm restructuring, making internal processes more flexible and rational, and reducing capital requirements, by improving equipment utilization and inventory reduction. Moreover, the possibility of developing better communication channels with suppliers, clients, knowledge providers, and competitors may increase innovation capacities.

Nevertheless, ICT-driven productivity gains vary largely among countries and sectors, suggesting that simple diffusion may be not sufficient to take full advantage of the potential of ICTs. Empirical evidence indicates that firm-specific operational and organizational characteristics determine not only the expected benefit deriving from ICT adoption, but also the actual impact once adopted. Therefore, complementary investment in areas such as organizational change and human capital appear necessary to both increasing absorptive capacity and maximizing the real impact of new technologies (Brynjolfsson and Hitt, 2000). As a result, ICTs seem to function as an “enabling factor” that allows firms to use new processes and business practices, which, in turn, generate performance improvements.

A complete understanding of these dynamics is central in order to design effective public policies to promote ICT adoption and increase firm productivity. However, the bulk of the literature has focused on developed countries, while evidence from emerging economies is still scarce and dispersed. This paper aims to fill in this knowledge gap, by exploring the determinants of broadband adoption and assessing their relationship with innovation and productivity in the context of Latin America and the Caribbean (LAC).

The rest of the paper is organized as follows. Section 2 describes the main patterns of Internet diffusion in Latin America and the data used in the empirical analysis. In Section 3 we discuss determinants of ICT adoption, while in Section 4 we explore the relationship between broadband, innovation and productivity. In each of these two sections, we review the relevant theoretical and empirical literature, specify the empirical model employed and discuss the main results. Finally, concluding remarks are provided in Section 5.

2. Data and main patterns of Internet diffusion in Latin America

ICT diffusion and use in Latin America and the Caribbean (LAC) is still relatively low. In fact, although ICTs have significantly increased their diffusion in the region, there is still a notable divide between LAC and developed countries, especially in most advanced technologies.[2] Using data from the International Telecommunications Union (ITU) for 2012, Figure 1 displays an international comparison for fixed-broadband penetration. Western Europe (EUR) and US-Canada appear at the top, with respectively 31 and 29 connections per 100 people. Eastern Europe and Central Asia (ECA) and East Asia and Pacific (EAP) appear far behind, with 12 connections per 100 people. The LAC region registers only 8 connections per 100 people, and Africa has less than one.

(Figure 1 about here)

With respect to ICT diffusion in firms, an international comparison is much more complicated, as it would require precise and comparable data, something not easy to find. Nevertheless, a first approximation can be made using data from the World Bank Enterprise Surveys (WBES).

The WBES have been conducted in various waves across 135 developing countries since 2002 through face-to-face interviews with top managers, covering a broad range of topics relevant to business and including innovation, ICT, access to finance, corruption, infrastructure, crime,

[2] Cathles, Crespi, and Grazzi (2011) performed a time-distance analysis to explore the pace at which the Latin American region is filling the digital gap with the OECD, finding that about 80 years would be necessary to reach OECD levels in terms of Internet subscriptions.

competition, and performance measures. However, a full set of ICT-related questions was only introduced in the 2010 round and not in all the surveyed countries[3].

For this reason, a comparison is possible only among those regions that have sufficient countries reporting data on ICT access. Figure 2 shows the level of broadband diffusion, use of email and availability of website in the surveyed firms, by region.

(Figure 2 about here)

In this context, LAC emerges as the region in the developing countries' sample with the highest level of ICT penetration, with almost 85% of its firms indicating that they have a high speed internet connection, 90% using e-mail to communicate with clients or suppliers[4] and 60% having their own website. This analysis shows that ICT diffusion among firms in the LAC region taken as a whole appears to generally be higher than in other developing regions. However, this result needs to be taken with some caution. First, the WBES does not provide information on the adoption and use of more advanced ICTs, but only of basic technologies, that firms in advanced region already take for granted. Considering this, the resulting picture could be too optimistic with respect to the real situation of the region. Second, WBES data on ICT diffusion in firms are not always consistent with ITU data on diffusion in the society, raising some concerns on data reliability. For example, Figure 3 shows the correlation between the percentage of households with a fixed broadband connection (ITU data) and the percentage of firms with broadband in their premises (WBES data) in the LAC region. It is clear that in some cases the two indicators substantially differ. For example, Panama shows a high level of household connection (31.6%), much higher than most Central American countries (with the exception of Costa Rica), but has the lowest percentage of firms with broadband connection, even lower than Nicaragua and Honduras.

(Figure 3 about here)

[3] For example, the 2009 Brazil survey included questions on broadband and ICT use in the questionnaire applied to the service sector, but not in the one applied to the manufacturing sector.
[4] The higher percentage of firms using e-mail compared to those having a broadband connection is explained by the fact that a simple internet connection (not necessarily in the firm's premises and not necessarily broadband) is required for the email.

Even considering these caveats, the WBES remains a privileged point of observation to empirically study ICT dynamics in LAC firms, as it is the first attempt to collect related data with the same questionnaire and sampling across all countries of the region. After data cleaning, the analysis included in this paper is based on a 2010 cross-section dataset of 10,477 enterprises from 19 LAC Countries[5], where Mexico (13.7%), Argentina (9.6%) and Chile (8.6%) are the countries most represented. The resulting sample includes enterprises of various sizes,[6] both from the manufacturing and the service sector. In Table 1, the main descriptive statistics of the sample are reported.

(Table 1 about here)

3. ICT Adoption

3.1. Background

From a theoretical point of view, several models have been developed to explain patterns of ICT adoption among firms, building on the existing body of research on technology diffusion. Karshenas and Stoneman (1995) proposed a general conceptual framework, distinguishing four different sub-models: "epidemic models," "rank (probit) models," "stock models," and "order models."

Early research introduced the so-called *epidemic models*, based on the concept that the diffusion of a technology basically depends on the information about its availability (Mansfield, 1963). These models predict that the diffusion of the new technology gradually increases over time, as adoption costs and risks decrease due to learning effects among firms. The process is similar to the spread of epidemics: early adopters disseminate information; other firms adopt the technology and release further information and so on until the saturation point. While epidemic models are traditionally based on information spillovers from users to non-users, in the case of ICT another dimension is very relevant: the existence of network effects. In fact, the gains

[5] Argentina, Bolivia, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay and Venezuela.

[6] 11% of the observations are large firms (over 250 employees), 28% medium firms (50-250 employees), 39% small firms (10-50 employees) and 22% micro firms (less than 10 employees).

deriving from ICT adoption – as well as the opportunity costs of not adopting - increase with the number of users of the technology, engendering a snowball effect.

However, these models, without considering firm heterogeneity, are not sufficient to fully explain variations in actual adoption rates among firms. Another group of theoretical models (rank or probit models) was developed with an increasing emphasis on the link between different firm characteristics, differentials in expected or potential returns, and adoption decisions.

Finally, two types of game theoretic approaches model the returns to adoption depending on the number of previous adopters and the order of adoption, respectively. *Stock models* are based on the assumption that the benefit from adoption decreases as the number of previous adopters increases. Then, for any given adoption cost there is a number of adopters beyond which adoption is not profitable. On the other hand, *order models* reflect the advantages of early adopters, assuming that returns to adoption depend on the position of a firm in the order of adoption, due to advantages such as obtaining better skilled labor or geographic locations.

It is important to stress that, even if the majority of the literature has focused on the demand side, technology diffusion dynamics are the result of the interaction between demand-side and supply-side factors. The presented models usually assume a fall in prices over time, but do not relate it to supply-side forces. Moreover, and quite surprisingly, empirical research has mainly focused on inter-firm diffusion – the access a firm has to a new technology - and has neglected intra-firm diffusion - the extent of technology usage in the firm.

3.2. Model Specification and Results

The paper, in line with recent literature, will test empirically the validity of the rank and epidemic[7] models in Latin American firms, focusing both on inter-firm and intra-firm ICT diffusion. With the objective of identifying determinants of inter-firm diffusion, we estimate the following equation in order to model the probability of a firm to adopt ICT:

$$\Pr(ICTADOPTION=1) = F(\alpha + \beta_0 * RankEffects + \beta_1 * LocationEffects + \beta_2 * EpidemicEffects + \beta_3 * CountryEffects + \beta 4 * SectorEffects) \quad (1)$$

[7] In the chapter we could not test stock and order models due to the lack of panel data.

To measure ICT inter-firm adoption, we consider two different dichotomic indicators: Broadband, taking the value of one if a firm has a high-speed Internet connection on its premises and Website, taking value of one if the establishment has its own website. Then, we estimate two equations where Broadband and Website are the dependent variables, respectively.

As for rank effects, we first consider the size of the firm, grouping them in four categories: micro (10 or less employees); small (11-50 employees); medium (51-250); large (251 or more). Large firms are taken as the reference group. Size is generally considered to be relevant in adoption of new technologies. In fact, given that larger firms have fewer financial constraints and are usually less risk adverse, they are supposed to be in a better position to sustain costs and risks of new technologies. Empirical evidence generally supports this hypothesis (Teo and Tan, 1998; Fabiani, Schivardi and Trento, 2005; Haller and Siedshlag, 2011; Giunta and Trivieri, 2007).[8]

We then consider the age of the firm, to proxy a firm's technological experience (variable *age*), and we proxy human capital via the percentage of workers with at least a bachelor degree (variable *skilled*). The relationship between a skilled workforce and ICT adoption is rather clear in the literature,[9] finding that a more educated workforce facilitates the early adoption of technologies (Chun, 2003) and that the demand for skilled workers increases with use of new technologies (Bartel and Sicherman, 1999); however the role of firm age is not theoretically straightforward. In fact, on the one hand, older firms are supposedly better equipped to assess the risks and benefits of the introduction of new technologies, but on the other hand, younger enterprises are supposed to be more flexible to organizational changes that come with the adoption of ICTs. The empirical evidence is inconclusive, finding in general either a non-significant impact (Bayo-Moriones and Lera-Lopez, 2007; Giunta and Trivieri, 2007) or negative impact (Haller and Siedschlag, 2011; Gambardella and Torrisi, 2001) of age on ICT diffusion.

The next two variables considered are the exposure to international competition and the necessity to be ICT early adopters to maintain a fluid communication with foreign partners. Export is a dummy variable that classifies a firm as an exporter if at least 10% of sales are exported; FDI is also a dummy variable, taking the value of one if at least 10% of the capital is foreign owned. In general, empirical evidence shows that firms that engage in foreign trade are

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[8] However, there are some studies that found a weak or insignificant correlation between size and ICT adoption (e.g. Lefebre et al. 2005; Love et al. 2005)

[9] See for example, Arvanitis (2005); Bresnahan, Brynjolfsson, and Hitt (2002); Fabiani et al. (2005).

more likely to adopt new technologies (Hollenstein, 2004; Lucchetti and Sterlacchini, 2004; Haller and Siedschlag, 2011). In regards to FDI, the literature generally considers foreign-owned firms as technology early-adopters, which can act as channels of diffusion in the society (Keller, 2004; Narula and Zanfei, 2005).

City is a dummy variable that takes the value of one if the firm is located in a capital or in a city with more than one million inhabitants, and it controls for location effects. The empirical literature demonstrates the influence of an urban or densely populated location on ICT adoption. Many arguments support this hypothesis, such as the proximity of suppliers, technology prices, and the availability of a qualified labor force (Galliano, Roux, and Filippi, 2001; Karlsson, 1995).

Epidemic effects are here represented by the variable *Epidemic*, which calculates the percentage of other firms having adopted a technology (broadband or website) in the same country and sector. This variable tests for the existence of network effects for ICT diffusion, following the hypothesis of the presence of positive spillovers of existing technology adopters on firms considering adoption. In other words, firms operating in more digitally advanced countries and sectors may face reduced costs and increased benefits. Finally, in all estimations we include country and 3-digit sector dummy variables to control for unobserved industry-specific and region-specific effects.

In order to estimate these two equations, we use a sequential approach. First we apply a probit model, a common econometric approach using maximum likelihood estimation (MLE). Nonetheless, a possible problem with this approach is that it is not always a fully efficient econometric procedure as it does not consider the correlation between firm choices in adopting broadband and having a website. Therefore, in order to consider this possible correlation, we complement the probit analysis with a bivariate probit model (Biprobit) (Greene, 2003). Marginal effects resulting from estimations with probit are showed in Table 2. The first two columns present results for broadband connection, while the third and fourth columns refer to having a website. Columns (1) and (3) correspond to the basic model; while columns (2) and (4) add the location and epidemic variables. Estimates with biprobit are presented in Table 3, where on the left side basic estimations are displayed and on the right side location and epidemic effects are added. Additionally, in order to check for sectorial differences, we split the sample between manufacturing and services. In Table 4 marginal effects from the disaggregated estimations with biprobit are reported.

(Table 2, 3, and 4 about here)

Overall, the results appear robust to all the specifications and are generally in line with the empirical findings of previous studies. The smaller the firm, the less likely it is to have both a broadband connection in their own premises and have a functioning website. The quality of human capital, measured as the percentage of workers with at least a bachelor's degree, appears to be an important determinant of adoption, confirming the importance of having skilled workforce in order to increase the technology absorptive capacity of a firm. An additional interesting result comes from the positive and significant – although small – coefficient of age. It seems to demonstrate that previous technological experience is more important for ICT adoption in Latin American firms than flexibility to organizational changes. These results hold for the entire sample, as well as for both the manufacturing and services sub-samples.

Also, exposure to competition on foreign markets, as measured by the export dummy, has in general a positive impact on the probability of a firm to adopt ICTs, with the only exception of service exporters in the case of broadband. On the contrary, we did not find any significant effect of foreign ownership on broadband connection, although it seemed to be important for having a website, especially in the case of the services sector.

Finally, as for location and epidemic effects, the estimations show the key role they play in ICT adoption. In all the specifications using the entire sample, a firm operating in a country and sector where there is a larger share of firms using ICTs has a bigger probability to adopt them. However, when the sample is spitted by sector, the epidemic effects lose significance in the case of manufacturing firms, suggesting that they can be particularly important for firms operating in the services sector. Moreover, the firms that are located in a capital or in a city with more than one million inhabitants are in general more likely to both have broadband connection and a website.[10] This may reflect lower technology costs, higher availability of trained human capital and a higher level of connectivity of potential partners (i.e. suppliers and clients). If we adopt an extended concept of epidemic effects, not limited to firms operating in the same sector,

[10] With the exception of the biprobit estimation in the service sector with broadband as independent variable.

this result complements the importance of the level of technological assimilation of the environment in which a firm is operating in order to determine its pace of adoption.

The basic model of intra-firm diffusion does not differ substantially from the inter-firm one, given that the level of penetration is supposed to depend on epidemic and rank effects. The first major difference is related to the form of the dependent variables. The WBES collects data on three different categories of Internet use: (i) making purchases for the establishment, (ii) delivering services to clients, and (iii) researching or developing ideas for new products and services. In order to measure intra-firm diffusion, we build an indicator related with the availability of broadband and the number of activities performed by a firm. Then, our dependent variable *intra-firm* is an indicator taking values (0, 1, 2, 3, 4) and we use an ordered probit model, which is an appropriate method if the dependent variables are measured on an ordinal scale.

However, this approach fails to take into account the correlation between broadband adoption and intensity of Internet use. In fact, broadband adoption entirely determines the extent of use, selecting firms that actually have the capabilities to perform activities. Therefore, in order to disentangle the determinants of inter-firm and intra-firm adoption, it is necessary to first complement the analysis with alternative econometric approaches, taking into account this sample selection. Then, we generalize the Heckman sample selection model (Heckman, 1979; Van de Ven and Van Praag, 1981), specifying an ordered probit with sample selection, where the first stage equation is the broadband inter-firm diffusion equation, including both location and epidemic effects.

Table 5 reports the estimated coefficients resulting both from the ordered probit model and from the ordered probit with sample selection on the whole sample and disaggregated by sector. In general, the estimates show a similar pattern to those for inter-firm diffusion. Human capital, age and international openness remain important drivers of ICT diffusion in most specifications. However, there are some interesting differences. First, in the ordered probit, firm size is negative and significant only for small and micro firms, while the coefficient for medium firms is significant only in the case of the service sector. Once the sample selection is controlled for, all the size coefficients become smaller and not significant in the case of manufacturing, while in the case of services the coefficients also become smaller, but they lose significance only in the case of medium firms. On the one hand, in the case of manufacturing, size does not seem to matter for intensity of use, once broadband is adopted. On the other hand, in the case of services, this result seems to indicate the existence of a dimension threshold, above which size does not matter for intra-firm diffusion. Furthermore, we did not find any strong statistical evidence related to being located in a city. It suggests that location effects are important in the decision to adopt broadband, but not for how extensively it is used. Finally, there is some evidence of a negative correlation between foreign ownership and intra-firm diffusion, but only in the manufacturing sector. This result is stronger in the ordered probit with sample selection model and can be related to the fact that manufacturing foreign investments in the region are concentrated in low value-added activities. Therefore, ICTs are especially important for communication with headquarters, but not for research and relations with providers and clients, the activities used to build the intensity index.

(Table 5 about here)

4. Broadband, Innovation and Productivity

4.1. Background

The economic impact of ICT has received considerable attention in the literature, and over the last few years, many firm-level empirical studies have identified multiple channels through which ICT can have a positive effect on firm performance. For example, Mack and Faggian (2013) state that ICTs have dramatically changed every aspect of modern life, including business management, which has been revolutionized by the new capacity of finding, sharing, and storing information.

In fact, ICTs have the potential to generate a large impact on the internal communication processes of a firm. For example, it is usually argued that ICTs can help reduce internal communication costs (Jorgenson, 2001), allowing quicker information processing, lower coordination costs, fewer supervisors required (reduction in labor costs), and easier facilitation the decision making process (Cardona et al., 2013; Arvanitis and Loukis, 2009; Atrostic et al., 2004; Gilchrist et al., 2001). In turn, the reduction in communication costs can spur additional investments (Colecchia and Schreyer, 2002).

Moreover, ICTs may enable the development of new processes and new work practices (Mack and Faggian, 2013), and facilitate substantial firm restructuring (Brynjolfsson and Hitt, 2000), making internal processes more flexible and rational, and reducing capital requirements through better equipment utilization and inventory reduction. These improvements may also allow firms to improve the quality of their outputs.

Also, the adoption of ICTs opens the possibility of better external communication channels with suppliers, clients and, other firms, facilitating innovation processes, arranging new distribution systems and prompting knowledge spillovers across firms and regions (Czernich et al., 2011). Cheaper information dissemination can facilitate the adoption of new technologies devised elsewhere. As knowledge is increasingly becoming crucial for economic activity, ICTs have the potential to generate more efficient external collaboration and promote the creation of new knowledge (Forman and Zeebroeck, 2010). From a market perspective, ICT development can contribute to lower entry barriers and to promote transparency, fostering competition and development of new products, processes and business models (Czernich et al., 2011).

ICTs have become a substantial part of the modern business environment (Cardona et al., 2013), allowing factor productivity gains in industries that are intensive in ICT utilization. Recent empirical research has found extensive evidence on ICT impact on innovation activities and performance. Brynjolfsson and Saunders (2010) provide a comprehensive survey on IT and innovation, stating that the lower communication and replication costs provided by IT can help firms to innovate through new products. Bertschek, Cerquera, and Klein (2013) find that broadband exhibits a positive and significant impact on innovation activity in a sample of German firms through the period of expansion of digital subscriber lines (DSL) (2001-2003), and that its impact seems to increase when controlling for endogeneity. Polder et al. (2010) show that ICT investment and usage constitute important drivers of innovation activity in Dutch manufacturing and service sectors. Broadband is particularly relevant in the service sector, where it is found to be positively related to product, process and organizational innovation, while in the case of the manufacturing sector, it is found to be significant only for product and organizational innovation. As for the LAC region, Santoleri (2013) provided evidence of the role of ICT as an enabler of product and process innovation for a sample of Chilean firms. He also provided evidence that advanced usage of ICT is needed to enhance the innovation enabling role of the new technologies.

Regarding ICTs' impact on productivity, several authors have found clear empirical evidence. In a seminal study, Brynjolfsson and Hitt (2003) explore the effect of computerization on productivity and output growth in a sample of US firms over the period 1987-1994, finding a positive relationship. This relationship has been confirmed over the years by several empirical studies in various contexts. For example, Hempell (2005) finds significant evidence of the productivity effects of ICT using a GMM estimator on panel data of German firms in the period 1994-1999. Arvanitis and Loukis (2009) and Kaiser and Bertschek (2004) confirm this finding using data from Greece and Switzerland, and Germany, respectively. For the LAC region, Gutierrez (2011) finds a positive and significant effect of ICT investments on labor productivity in Colombian manufacturing enterprises.

However, the impact of ICT may be conditioned by certain characteristics of the internal context of the firm. In particular, some authors have highlighted the importance of complementary investments, pointing out that ICT adoption may increase its productivity impact if combined with human capital investment or internal restructuring (Brynjolfsson and Hitt, 2000). Knowledge stock and skills constitute determinants of absorptive capacity, which may influence firm capabilities to make the most of new technologies (Benhabib and Spiegel, 1994; Cohen and Levinthal, 1990). Organizational complements and intangible assets are considered crucial for ICT influence on productivity (Cardona et al., 2013). The economic impact of ICT may also depend on the sector of activity. In that sense, service-related firms may benefit more from ICT than companies belonging to other sectors.[11]

External factors may also be important in determining the impact dimension. In fact, ICT effects can be larger if a firm has strong linkages with external organizations. Network externalities may also be present, whereby the benefits of having adopted a technology depend on the adoption decisions of other users. As for internet connection, the economic returns to connectivity should rise once a certain threshold of connectivity penetration in the society is achieved.

Clearly, the concept of ICT includes a variety of different technologies, with different potential impact on firm's performance. Recently, broadband internet connection has been indicated as one of the most effective, because of its potential to enable a wide set of productivity-enhancing services. Some authors argue that broadband has become a necessary part of the infrastructure needed for economic and social development, comparing it to historic advances such as railroads, roads, and electricity (Mack and Faggian, 2013; and Jordan and De León, 2011).

In this section we contribute to the existing literature by empirically studying the impact of broadband adoption on firm performance in LAC, a region that has been understudied in relevant academic research. First we analyze the relationship with innovation activities and then we focus on the impact on firm productivity.

4.2. Empirical Models

To explore the link between broadband and innovation, we estimate the following equation, modeling the probability of a firm to carry out an innovation activity:

$$\Pr[INNOVATION = 1] = f(\delta + \gamma Broadband + \beta_X X)$$

[11] Service sector companies tend to use ICTs more intensively. Additionally, Crandall et al (2007) argue that the fact that individuals use broadband at home to connect to their business offices or even to telecommute makes more likely to be important in the service industries, such as finance, real estate, or miscellaneous business center.

To measure innovation activity, we consider two different binary variables: *Process Innovation*, taking the value of one if a firm has introduced a new or significantly improved process for producing or supplying products over the last 3 years; and *Product Innovation*, taking the value of one if the firm has introduced a new of significantly improved product (goods or services) over the last three years. *Broadband* is a dummy variable taking the value of one if the firm has a high-speed Internet connection on its premises.

Control variables X are also included, to account for other elements which may influence innovation activity at the firm-level. As in the case of technology diffusion, we will consider the age of the firm to proxy its technological experience (variable *age*), and we will proxy human capital with the percentage of workers with at least a bachelor's degree (variable *Human Capital*). As in Bertschek et al. (2013), investment will be included to explain innovation. In this case, it will be approximated by a dummy variable taking the value of one if the enterprise has bought a fixed asset in the last year, such as machinery, vehicles, equipment, land or buildings.

We included four firm size variables (*Micro*, *Small*, *Medium* and *Large*) as innovative activity may depend on the size of the enterprise. Past research has found that big companies can amortize sunk costs related to innovation activity, present more capacity for risk diversification, and have lower financial constraints (see for example Acs and Audretsch, 1988; or Cohen and Klepper, 1996). Moreover, we included *Export* and *FDI* as control variables. In fact, it is possible that companies exposed to international markets face a stronger pressure to innovate, in order to remain competitive. *FDI* may also constitute a channel for international knowledge spillovers, if the organizational structure and governance of the multinational companies allows it. Finally, the fact that a firm is located in an urban or densely populated area can contribute to generate agglomeration economies which may have an impact on firm performance. This is measured through the variable *Capital City*. In all estimations we include country and 3-digit sector dummy variables to control for unobserved industry-specific and country-specific effects.

In order to estimate the proposed equation, we first use a simple probit model. Nevertheless, this approach can give biased results due to endogeneity (either deriving from reverse causality or unobservables). Given this, we complement it with a bivariate recursive probit, instrumenting broadband access with a variable representing the use of e-mail by a firm.[12] Additionally, we extend the analysis, by considering not only broadband adoption, but also the degree of exploitation of its potential. To do so, we run additional regressions including a dummy variable for the use of each of the following three internet activities: making purchases for the establishment, delivering services to clients, and researching or developing ideas on new products and services. This information is collected through the survey only for the firms which have a broadband connection on their premises. Finally, we include an indicator of intensity of use, represented by a dummy variable taking value of one if a firm performs all the three activities.

To analyze the impact of broadband on labor productivity, we used a model in which firms are supposed to produce according to a Cobb-Douglas production technology with constant returns to scale on physical capital and labor:

$$Y = AK^{\alpha}L^{1-\alpha}$$

Where Y represents output, K is physical capital stock, and L is labor. The term A represents total factor productivity (TFP), which may be affected by the availability of broadband internet connection, and by a vector of control variables X:

$$A = f(Broadband, X)$$

Combining both expressions and applying logarithms to linearize the empirical specification:

$$\ln\left[\frac{Y}{L}\right] = \delta + \alpha \ln\left[\frac{K}{L}\right] + \gamma Broadband + \beta_X X$$

Labor productivity is measured as sales per employee. Physical capital is approximated as the replacement value of machinery, vehicles and equipment. Among controls X, we include some of the previously defined variables: *Firm Size*, *Age*, *Human Capital*, *Export*, *FDI* and *City*. We also include an *Innovation* dummy variable which takes value 1 if the firm has introduced either a product or a process innovation. In all estimations we add country and 3-digit sector dummy variables to control for unobserved effects. The unexplained part of the TFP will be captured by the dummy variables and the constant term δ. As in the case of innovation activities, we run additional estimations considering the use of Internet for specific activities and the intensity of use. We control for potential endogeneity by using an instrumental variable (IV) approach to

[12] E-mail utilization is expected to be closely related to broadband adoption. On the contrary, as e-mail has become massively diffused several years ago, there are not obvious reasons for relating it to higher firm performance nowadays. Our data analysis confirms these expectations.

complement the standard analysis. For that purpose, also in this case e-mail utilization at the firm level is used to instrument broadband.

4.3. Estimation Results

Table 6 summarizes estimation results for determinants of innovation activities. As the coefficients of probit and biprobit models do not have a direct interpretation, we present average marginal effects, representing the average percentage change in the probability of introducing a product or process innovation. Columns (1) through (4) display the results for new product innovation, while columns (5) through (8) correspond to new process innovation. In the biprobit estimations the *Rho* term, which measures the correlation among the residuals of the innovation and broadband adoption equations, is negative and significant in all the specifications. This means that biprobit is probably the most accurate model, as it controls for the endogeneity caused by the presence of unobservables and for possible reverse causality.

(Table 6 about here)

Broadband shows a significant and positive impact on the probability of a firm introducing both a product and a process innovation in the specifications which do not consider the different internet uses (columns 1, 3, 5, 7).[13] In all these cases the significance level is at 1%. However, when we introduce the variables for different Internet uses (columns 2, 4, 6, 8) the coefficient for broadband adoption is no longer significant[14] and some interesting results arise. First, as expected, the use of Internet to perform research is clearly related to both product and process innovation. In all cases the significance level is 1% and the average marginal effect is in the order of 11%.[15] Second, the use for delivering services for clients is not significant for product innovation, but it is positively correlated to process innovation. This result seems to

[13] It is interesting to notice that once possible endogeneity between innovation and broadband is taken into account, the impact of broadband on innovation activity seems to be higher. This result is similar to what was found by Bertschek et al (2013) and it can be explained by the fact that the adoption of broadband could induce a process of internal reorganization that may reduce the contribution of some existing practices to innovation activity.
[14] The only exception is specification 8 in which *Broadband* remains positive at a 5% level.
[15] To check the robustness of this result, different estimations were performed adding as controls alternative measures of R&D spending, and in all cases the use of internet for research remained positive and significant.

confirm that Internet may promote innovation by enabling new distribution schemes. Third, the use for purchases was found to be not positively related to any innovation activity.

As for the intensity indicator, in all cases it is found to be positively related with innovation activity and suggests that the combined use of broadband for different activities is relevant beyond the individual uses. In fact, firms using the Internet for all the three activities increase their probability to innovate approximately a further five percent.[16] Overall, these results seem to confirm the hypothesis that simple access to technology is not sufficient to obtain a performance improvement, but that using it adequately is necessary in order to fully exploit its potential.

Among control variables, being a large firm is positively associated with probability of innovation. In fact, the micro, small and medium firm coefficients are, in most cases, significant and negative, showing that the baseline scenario (large firms) is the most propitious for both product and process innovation. While micro firms are associated with the lowest probability of product innovation, this gap does not seem to exist in the case of process innovation. As for the coefficient associated with human capital, it is in most cases positive and significant, reflecting the importance of having internal skills to promote innovation. The coefficient of the variable *Exporter* is also positive and significant in most cases, reflecting the fact that companies competing in international markets present a higher propensity for innovation activity. Nevertheless, being foreign owned does not seem to increase the probability of innovation in a firm, as the coefficients for *FDI* are either not significant or negative. A possible explanation for this situation is related to the fact that multinational enterprises usually concentrate R&D and innovation activities at headquarters and not in their subsidiaries abroad. Finally, the coefficient associated with *Investment* is positive and significant at 1% level, while in most cases, no statistical relationship was found between innovation and the age of the firm or agglomeration effects (measured by the variable *City*).

Table 7 summarizes the results of the estimations of the determinants of firm productivity. OLS results are presented in columns 1-2, while the results for the instrumental variables are displayed in columns (3) and (4). As in the case of innovation activities, *Broadband* has a positive and significant impact on the labor productivity of LAC firms, and its coefficient increases when we control for endogeneity.

[16] The marginal effect in the case of product innovation is slightly higher than in those of process innovation.

However, when we introduce *Internet use* variables in the OLS estimation, *Broadband adoption* remains positive and significant, while the coefficients for single activities and intensity indicator do not appear to be relevant. In the case of the instrumental variables estimation, we find positive and significant coefficient for the *Intensity of use*, but negative sign for *Delivering services and performing research*. A possible explanation of these results may be related to the typology of Internet uses considered in the survey. On the one hand, such activities could have an impact on productivity only with a time lag. As we are not working with time-series data, we cannot consider this aspect. Also, the negative signs of some individual activities coefficients may be linked to the fact that these uses can induce short-term costs for the firm in terms of complementary investment, without immediate benefits. On the other hand - as the adoption indicator remains positive and highly significant in all estimations - the impact of broadband on productivity may be related to alternative uses, such as, for example, reduction in internal communication costs, improvements in the process of decision taking, development of new internal process or work practices and firm restructuring. Finally, the positive and significant coefficient of the intensity indicator in the IV estimation confirms the importance of simultaneously using ICTs in various aspects of business activity in order to obtain productivity gains.

(Table 7 about here)

As expected, the coefficients for physical capital per worker and investment are positive and highly significant, as well as those for human capital, exporter status, and presence of FDI. On the contrary, having performed innovation seems to be not relevant for labor productivity in these estimations. Also in this case, a possible explanation may refer to the time-lag necessary to translate innovation activities into productivity gains. Another possibility is that part of the innovation effect is already captured by the *Broadband* variable.

5. Final Remarks

This paper contributes to the empirical literature on technology diffusion and impact, identifying determinants of ICT adoption and exploring the link between broadband use, innovation and productivity in Latin American firms. We analyzed both inter-firm and intra-firm diffusion patterns, finding that the ICT adoption behavior of Latin American firms is characterized by a basic set of determinants which is quite robust across model estimations and different variable specifications. We find evidence of the presence of both epidemic and rank effects, where larger, older, skill-intensive, exporter and urban firms are more likely to adopt ICTs. However, once adopted, size and location lose importance.

Additionally, we find robust empirical evidence on the positive relationship between broadband and firm performance. In particular, the adoption of broadband in firms increases the probability of innovating. This effect seems to be mainly related to its use in research and development and to the intensity of use, proxied by the combined use of various activities. Further estimations also provide evidence that broadband adoption and use constitute a source of productivity growth for Latin American firms. These results are aligned with previous ICT literature in the developed world, which suggests that broadband plays an important role as an innovation enabler and productivity enhancer.

The availability of novel empirical evidence specific for Latin America may offer useful insights to policymakers for the design and implementation of initiatives aimed at fostering productivity by increasing broadband connectivity. In fact, nowadays several regional countries are investing a considerable amount of resources in initiatives such as the “Plano Nacional de Banda Larga” in Brazil or the “Vive Digital” plan in Colombia.

However, our analysis has been limited by data availability and it should be complemented by future research. For example, the role of complementarities (e.g. human capital or organizational innovations) and network externalities in increasing the gains derived from ICT adoption remain largely understudied in the empirical literature on Latin America. Further research could also look at the role of the national ICT industry. For example, the ability of a country to produce software adapted to the needs of local firms may play a role not only on ICT adoption decisions, but also on the impact of ICTs on firm performance, once adopted. These extensions may provide a deeper understanding of the linkages between ICTs and firm performance and on the characteristics that effective public policies should have.

References

Acs, Z.J. and D. Audretsch. 1988. "Innovation in Large and Small Firms: An Empirical Analysis." *American Economic Review*, American Economic Association 78(4): 678-90.

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

Arvanitis, S. and E.N. Loukis. 2009. "Information and Communication Technologies, Human Capital, Workplace Organization and Labour Productivity: A Comparative Study Based on Firm-Level Data for Greece and Switzerland." *Information Economics and Policy* 21(1): 43-61.

Atrostic, B. K., P. Boegh-Nielsen, K. Motohashi, and S. Nguyen. 2004. "IT, Productivity and Growth in Enterprises: Evidence from New International Micro Data." *The Economic Impact of ICT–Measurement, Evidence and Implications*.

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

Bartel, A.P. and N. Sicherman. 1999. "Technological Change and Wages: An Interindustry Analysis." *Journal of Political Economy* 107(2): 285-325.

Benhabib, J. and M. Spiegel. 1994. "The Role of Human Capital in Economic Development. Evidence from Aggregate Cross-Country Data." *Journal of Monetary Economics* 34: 143-173.

Bertschek, I., D. Cerquera, and G.J. Klein. 2013. "More Bits–More bucks? Measuring the Impact of Broadband Internet on Firm Performance." *Information Economics and Policy* 25(3): 190-203.

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

Brynjolfsson, E., and L.M. Hitt. 2000. "Beyond Computation: Information Technology, Organizational Transformation and Business Performance." *The Journal of Economic Perspectives*: 23-48.

----. 2003. "Computing Productivity: Firm-Level Evidence." *Review of Economics and Statistics* 85(4): 793-808.

Brynjolfsson, E. and A. Saunders. 2010. *Wired for Innovation*. Cambridge, United States: MIT Press.

Cardona, M., T. Kretschmer, and T. Strobel. 2013. “ICT and Productivity: Conclusions from the Empirical Literature.” *Information Economics and Policy* 25(3): 109-125.

Cathles, A., G. Crespi, and M. Grazzi. 2011. “The Region’s Place in the Digital World: A Tale of Three Divides.” In A. Chong, *Development Connections. Unveiling the Impact of New Information Technologies*. Washington, D.C.: Inter-American Development Bank.

Chun, H. 2003. “Information Technology and the Demand for Educated Workers: Disentangling the Impacts of Adoption versus Use.” *Review of Economics and Statistics* 85: 1–8.

Cohen, W. M. and S. Klepper. 1996. “Firm Size and the Nature of Innovation within Industries: The Case of Process and Product R&D.” *The Review of Economics and Statistics*. 78(2): 232-43.

Cohen, W. M. and D. Levinthal. 1990. “Absorptive Capacity: A New Perspective on Learning and Innovation.” *Administrative Science Quarterly* 35(1).

Colecchia, A. and P. Schreyer. 2002. “ICT Investment and Economic Growth in the 1990s: Is the United States a Unique Case? A Comparative Study of Nine OECD Countries.” *Review of Economic Dynamics* 5: 408-442.

Crandall, R.W., W. Lehr, and R. Litan. 2007. “The Effects of Broadband Deployment on Output and Employment: A Cross-Sectional Analysis of US Data.” *Brookings Institution*.

Czernich, N., O. Falck, T. Kretschmer, and L. Woessmann. 2011. “Broadband Infrastructure and Economic Growth.” *The Economic Journal* 121(552): 505-532.

Fabiani, S., F. Schivardi, and S. Trento. 2005. “ICT Adoption in Italian Manufacturing: Firm Level Evidence.” *Industrial and Corporate Change* 14: 225–49.

Forman, C. and N. van Zeebroeck. 2010. “From Wires to Partners: How the Internet has Fostered R&D Collaborations Within Firms.”

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

Gambardella, A. and S. Torrisi. 2001. “Nuova industria o nuova economia? L‛‛impatto della informatica sulla produttivita` dei settori manifatturieri in Italia.” *Moneta e Credito* 54(213): 39-76.

Gilchrist, S., V. Gurbaxani, and R. Town. 2001. "Productivity and the PC Revolution." *Center for Research on Information Technology and Organizations Working paper, University of California.*

Giunta, A. and F. Trivieri. 2007. "Understanding the Determinants of Information Technology Adoption: Evidence from Italian Manufacturing Firms." *Applied Economics* 39: 1325–34.

Greene, W.H. 2003. *Econometric Analysis, 5th*. Upper Saddle River, NJ: Prentice Hall.

Gutiérrez, L.H. 2011. "ICT and Labor Productivity in Colombian Manufacturing Industry." In M. Balboni, S. Rovira and S. Vergara, *ICT in Latin America: A Microdata Analysis*. Santiago, Chile: United Nations.

Haller, S.A. and I. Siedhlag, I. 2011. "Determinants of ICT Adoption: Evidence from Firm-Level Data." *Applied Economics* 43: 3775–3788.

Heckman, J. 1979. "Sample Selection Bias as a Specification Error." *Econometrica* 47(1): 153-161.

Hempell, T. 2005. "Does Experience Matter? Innovations and the Productivity of Information and Communication Technologies in German Services." *Economics of Innovation and New Technology*. 14(4): 277-303.

Hollenstein, H. 2004. "Determinants of the Adoption of Information and Communication Technologies: An Empirical Analysis Based on the Firm-Level Data for the Swiss Business Sector." *Structural Change and Economic Dynamics* 15(3): 315–342.

Jordan, V. and O. De León. 2011. "Broadband and the Digital Revolution." In V. Jordan, H. Galperín, and W. Peres, *Fast-Tracking the Digital Revolution: Broadband for Latin American and the Caribbean*. Santiago, Chile: United Nations.

Jorgenson, D.W. 2001. "Information Technology and the US Economy." *American Economic Review* 91(1): 1-32.

Kaiser, U., and I. Bertschek. 2004. "Productivity Effects of Organizational Change: Microeconometric Evidence." *Management Science* 50(3): 394-404.

Karlsson, C. 1995. "Innovation Adoption, Innovation Networks and Agglomeration Economies." In C.S. Bertuglia, M.M. Fischer, and G. Preto, *Technological Change, Economic Development and Space*. Berlin, Germany: Springer.

Karshenas, M., and P. Stoneman. 1995. “Technological Diffusion.” In P. Stoneman, *Handbook of the Economics of Innovation and Technological Change*. Blackwell, Oxford.

Keller, W. 2004. International technology diffusion, *Journal of Economic Literature* 42: 752–82.

Mack, E. and A. Faggian, A. 2013. “Productivity and Broadband: The Human Factor.” *International Regional Science Review* 00(0): 1-32.

Mansfield, E. 1963. “Intra-Firm Rates of Diffusion of an Innovation.” *Review of Economics and Statistics* 45: 348–59.

Narula, R. and A. Zanfei. 2005. “Globalization of Innovation: The Role of Multinational Enterprises.” In J. Fagerberg, D. Mowery and R. Nelson, *The Oxford Handbook of Innovation*. New York: Oxford University Press.

Oliner, S.D., and D. Sichel. 1994. “Computers and Output Growth: How Big is the Puzzle?” *Brookings Papers in Economic Activity* 2: 273–334.

---- 2002. “Information Technology and Productivity: Where Are We Now and Where Are We Going?” *Federal Reserve Bank of Atlanta Review* 87(3): 15–44.

Polder, M., G. van Leeuwen, P. Mohnen, and W. Raymond. 2010. “Product, Process and Organizational Innovation: Drivers, Complementarity and Productivity Effects.” *UNU-MERIT*.

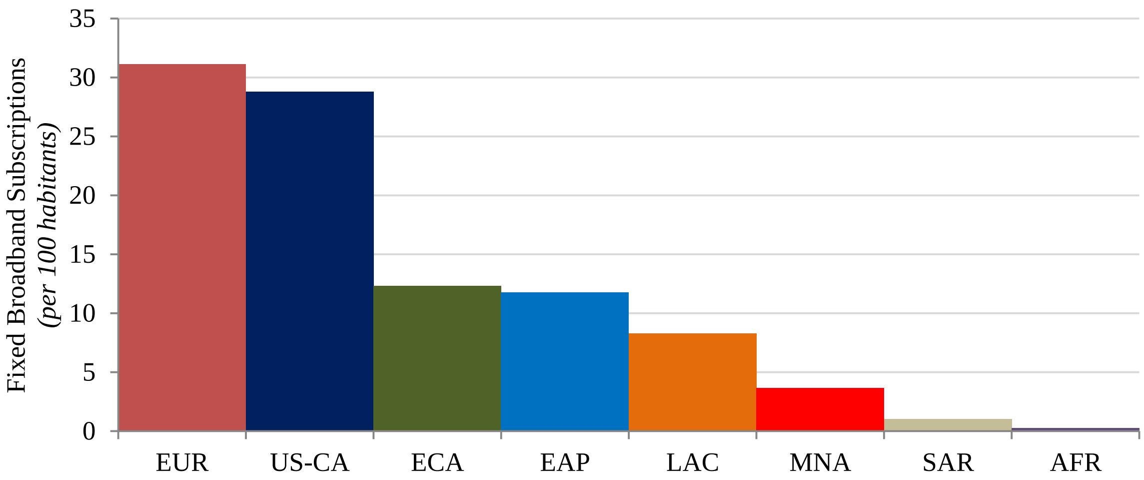
Santoreli, P. 2013. “Diversity and Intensity of ICT Use Effects on Product Innovation: Evidence from Chilean Micro-Data.” Paper presented at UNU-MERIT conference on *Micro Evidence on Innovation and Development*, Santiago de Chile: November 7-8, 2013.

Teo, T.S.H. and M. Tan. 1998. “An Empirical Study of Adopters and Non-Adopters of the Internet in Singapore.” *Information and Management* 34: 339–45.

Van de Ven, W.P.M. and B. Van Praag. 1981. “The Demand for Deductibles in Private Health Insurance: A Probit Model with Sample Selection.” *Journal of Econometrics* 17: 229-252.

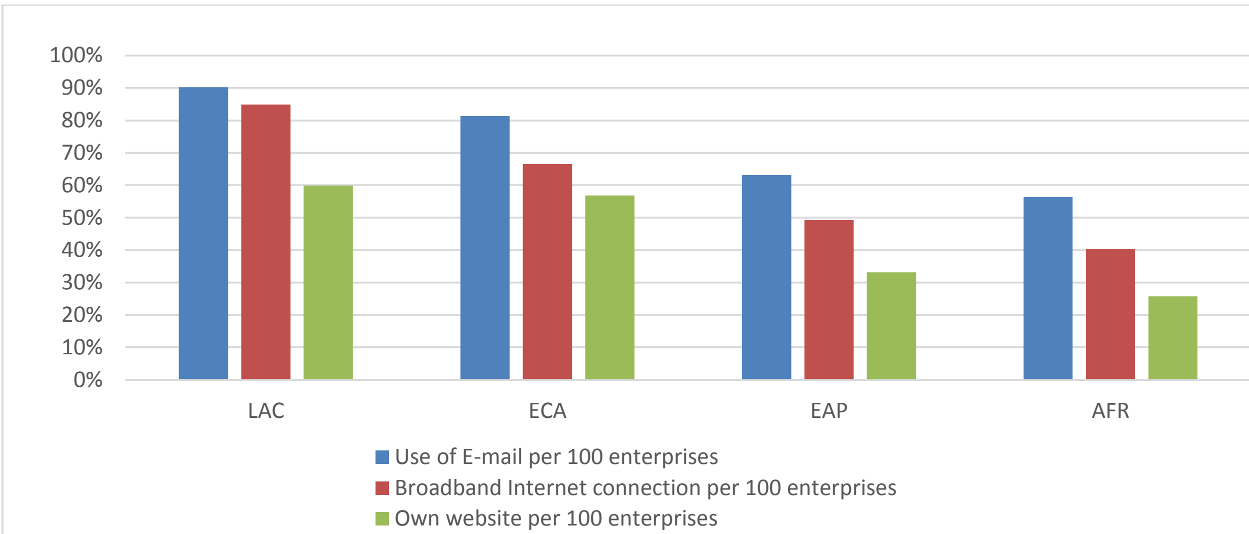
Appendix A: Tables and Figures

Figure 1: Fixed Broadband Subscriptions by Region (2012)



Source: Authors' elaboration using data from the WBES

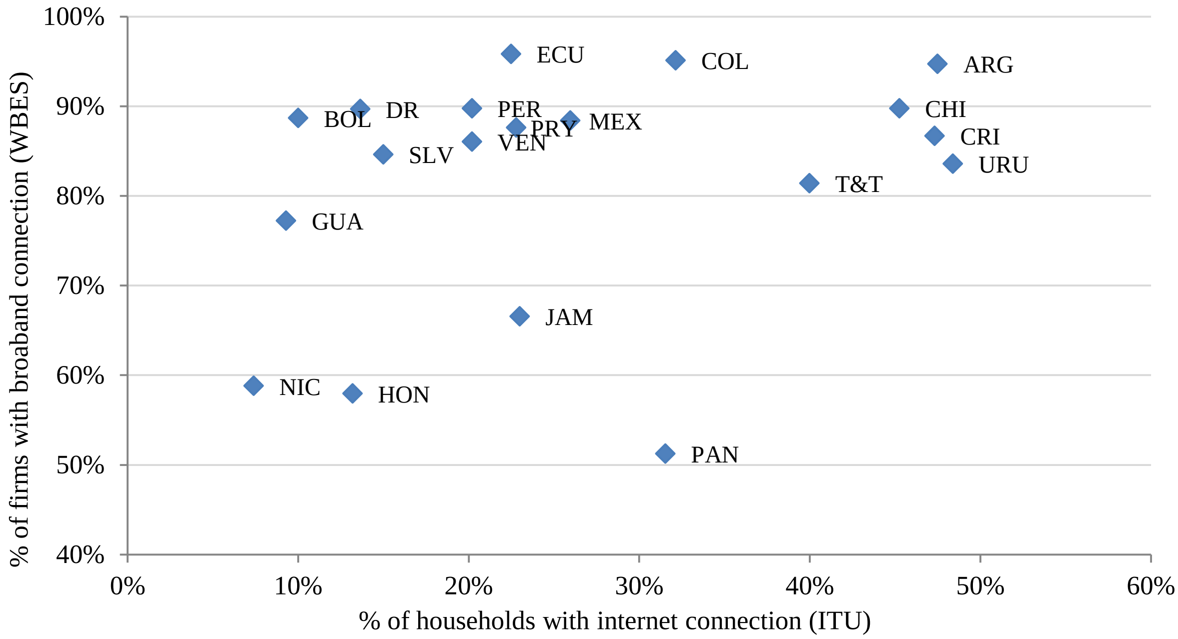
Figure 2: ICT Diffusion in Enterprises (2009- 2010)



Source: Authors' elaboration using data from the WBES

Notes: Simple average of available countries in each region. **LAC**: Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, St Kitts and Nevis, St Lucia, St Vincent and Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela.**ECA**: Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Czech Republic, Estonia, Fyr Macedonia, Hungary, Kazakhstan, Kosovo, Kyrgyz Republic, Latvia, Lithuania, Moldova, Mongolia, Montenegro, Poland, Romania, Russia, Serbia, Slovak Republic, Slovenia **EAP**: Fiji, Indonesia, Lao PDR, Micronesia, Philippines, Samoa, Timor Leste, Tonga, Vanuatu, Vietnam. **AFR**: Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Congo, Eritrea, Gabon, Ivory Coast, Lesotho, Liberia, Madagascar, Malawi, Mauritius, Niger, Sierra Leone, Togo, Angola, Botswana, DRC, Mali

Figure 3: ICT Diffusion in Latin American Countries (Latest Available Year)



Source: Authors' elaboration using data from ITU and WBES.

Table 1. Descriptive Statistics

Variables	Mean	Standard Deviation	Minimum	Maximum	Observations
Broadband	0.848	0.359	0	1	10440
Email	0.904	0.295	0	1	10462
Internet Use for Purchases	0.626	0.484	0	1	10440
Internet Use to Deliver Services	0.605	0.489	0	1	10440
Internet Use for Research	0.674	0.469	0	1	10440
Internet for Purchases + Deliver Services + Research	0.429	0.495	0	1	10440
Broadband Intensity (Scale)	2.752	1.426	0	4	10440
Log (Productivity)	10.426	1.200	4.06	16.34	8431
New Product	0.574	0.495	0	1	6155
New Process	0.483	0.500	0	1	6147
Log (Capital per worker)	8.706	1.546	1.09	14.95	4293
Micro Firm	0.219	0.414	0	1	10440
Small Firm	0.394	0.489	0	1	10440
Medium Firm	0.277	0.448	0	1	10440
Human Capital	16.864	21.635	0	100	10165
Age of Firm	25.898	20.036	1	185	10330
FDI	0.129	0.336	0	1	10477
Exporter	0.162	0.369	0	1	10477
Investment	0.555	0.497	0	1	10415
Capital City	0.497	0.500	0	1	10477

Source: Authors' elaboration.

Table 2. Determinants of Broadband Connection and Using Firm Website: Probit Estimations

Variables	Broadband Connection		Website	
	(1)	**(2)**	**(3)**	**(4)**
Micro Firm	-0.274***	-0.268***	-0.475***	-0.465***
	(0.0183)	(0.0182)	(0.0194)	(0.0194)
Small Firm	-0.145***	-0.142***	-0.307***	-0.302***
	(0.0182)	(0.0181)	(0.0190)	(0.0190)
Medium Firm	-0.0644***	-0.0617***	-0.118***	-0.115***
	(0.0188)	(0.0187)	(0.0199)	(0.0199)
Skilled Human Capital	0.0021***	0.0021***	0.0023***	0.0023***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Age of firm	0.0007***	0.0006***	0.0013***	0.0013***
	(0.0001)	(0.0002)	(0.0002)	(0.0002)
FDI	0.0155	0.0120	0.0560***	0.0538***
	(0.0122)	(0.0121)	(0.0150)	(0.0151)
Exporter	0.0808***	0.0828***	0.1060***	0.1080***
	(0.0142)	(0.0143)	(0.0142)	(0.0143)
Capital City	n.a.	0.0241***	n.a.	0.0458***
		(0.0070)		(0.0092)
Epidemic (broadband)	n.a.	0.112***	n.a.	n.a.
		(0.0324)		
Epidemic (website)	n.a.	n.a.	n.a.	0.1430***
				(0.0351)
Country Dummies	Yes	Yes	Yes	Yes
Sector Dummies	Yes	Yes	Yes	Yes
Log Likelihood	-3045	-3017	-5026	-4981
Pseudo R-squared	0.276	0.279	0.237	0.239
Observations	9,668	9,616	9,977	9,910

Source: Authors' own elaboration

Notes: Estimated marginal effects from the probit regression. Delta-method standard errors are in parentheses. * Coefficient is statistically significant at the 10 percent level; ** at the 5 percent level; *** at the 1 percent level; no asterisk means the coefficient is not different from zero with statistical significance. n.a. = not applicable.

Table 3. Determinants of Broadband Connection and Using Firm Website: Bivariate Probit Estimations

Variables	Broadband (1)	Website (2)	Broadband (3)	Website (4)
Micro Firm	-0.266***	-0.472***	-0.261***	-0.463***
	(0.0175)	(0.0192)	(0.0175)	(0.0192)
Small Firm	-0.141***	-0.305***	-0.138***	-0.300***
	(0.0174)	(0.0188)	(0.0174)	(0.0188)
Medium Firm	-0.0626***	-0.117***	-0.0598***	-0.114***
	(0.0181)	(0.0196)	(0.0180)	(0.0196)
Skilled Human	0.0020***	0.0023***	0.0020***	0.0024***
Capital	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Age of firm	0.0006***	0.0013***	0.0006***	0.0013***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
FDI	0.0148	0.0563***	0.0109	0.0538***
	(0.0117)	(0.0149)	(0.0117)	(0.0150)
Exporter	0.0805***	0.104***	0.0822***	0.106***
	(0.0139)	(0.0140)	(0.0140)	(0.0141)
Capital City	n.a.	n.a.	0.0226***	0.0454***
			(0.0068)	(0.0092)
Epidemic (broadband)	n.a.	n.a.	0.107***	n.a.
			(0.0303)	
Epidemic (website)	n.a.	n.a.	n.a.	0.149***
				(0.0341)
Country Dummies	Yes	Yes	Yes	Yes
Sector Dummies	Yes	Yes	Yes	Yes
Log Likelihood	-7865		-7796	
Rho	0.444		0.444	
	(0.020)		(0.021)	
/athrho	0.477		0.477	
	(0.025)		(0.025)	
Observations	10,019		9,950	

Source: Authors own elaboration

Notes: Estimated marginal effects from the biprobit regression. Delta-method standard errors in parentheses. * Coefficient is statistically significant at the 10 percent level; ** at the 5 percent level; *** at the 1 percent level; no asterisk means the coefficient is not different from zero with statistical significance. n.a. = not applicable.

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Table 4. Determinants of Broadband Connection and Using Firm Website: Bivariate Probit Estimations by Sector

Variables	Manufacturing		Services	
	Broadband (1)	**Website (2)**	**Broadband (3)**	**Website (4)**
Micro Firm	-0.255***	-0.470***	-0.267***	-0.450***
	(0.0229)	(0.0247)	(0.0271)	(0.0310)
Small Firm	-0.145***	-0.302***	-0.123***	-0.299***
	(0.0227)	(0.0240)	(0.0269)	(0.0307)
Medium Firm	-0.0490**	-0.126***	-0.0699**	-0.0928**
	(0.0240)	(0.0246)	(0.0274)	(0.0325)
Skilled Human Capital	0.0017***	0.0030***	0.0022***	0.0019***
	(0.0003)	(0.0004)	(0.0003)	(0.0003)
Age of firm	0.0004**	0.0015***	0.0010***	0.0008**
	(0.0002)	(0.0003)	(0.0003)	(0.0004)
FDI	0.0047	0.0141	0.0225	0.105***
	(0.0166)	(0.0199)	(0.0171)	(0.0225)
Exporter	0.0871***	0.0957***	0.0446	0.164***
	(0.0151)	(0.0150)	(0.0332)	(0.0408)
Capital City	0.0278***	0.0336***	0.0161	0.0647***
	(0.00868)	(0.0119)	(0.0110)	(0.0148)
Epidemic (broadband)	0.0148	n.a.	0.159***	n.a.
	(0.0364)		(0.0604)	
Epidemic (website)	n.a.	0.0544	n.a.	0.158**
		(0.0429)		(0.0612)
Country Dummies	Yes	Yes	Yes	Yes
Sector Dummies	Yes	Yes	Yes	Yes
Log Likelihood	-4645		-3092	
Rho	0.407		0.510	
Observations	6,147		3,803	

Source: Authors' own elaboration

Notes: Estimated marginal effects from the Bi-probit regression. Delta-method standard errors in parentheses. * Coefficient is statistically significant at the 10 percent level; ** at the 5 percent level; *** at the 1 percent level; no asterisk means the coefficient is not different from zero with statistical significance. n.a. = not applicable.

Table 5. Determinants of Broadband Intensity of Use: Ordered Probit and Ordered Probit with Sample Selection Estimations

Variables	Ordered Probit			Ordered Probit with Sample Selection		
	Whole	Manufacturin	Services	Whole	Manufacturin	Services
Micro Firm	-0.864***	-0.862***	-0.872***	-0.154***	-0.118	-0.252**
	(0.0474)	(0.0615)	(0.0770)	(0.0597)	(0.0744)	(0.121)
Small Firm	-0.304***	-0.286***	-0.331***	-0.110**	-0.0565	-0.199**
	(0.0422)	(0.0541)	(0.0695)	(0.0470)	(0.0600)	(0.0818)
Medium Firm	-0.0676	-0.00706	-0.168**	-0.0368	0.000484	-0.108
	(0.0415)	(0.0519)	(0.0700)	(0.0456)	(0.0570)	(0.0791)
Skilled Human Capital	0.0069***	0.0067***	0.0070***	0.0021***	0.0031***	0.0018
	(0.0007)	(0.0010)	(0.0009)	(0.0007)	(0.0010)	(0.0011)
Age of firm	0.0025***	0.0020***	0.0035***	0.0016**	0.0016*	0.0018
	(0.0006)	(0.0008)	(0.0011)	(0.0007)	(0.0008)	(0.0012)
FDI	-0.0601	-0.105**	0.007	-0.0771*	-0.115**	-0.0194
	(0.0372)	(0.0495)	(0.0565)	(0.0394)	(0.0513)	(0.0621)
Exporter	0.225***	0.226***	0.210**	0.107***	0.0872**	0.200**
	(0.0353)	(0.0394)	(0.0897)	(0.0375)	(0.0421)	(0.0947)
Capital City	0.0380	0.0172	0.0652	-0.0383	-0.0852**	0.0310
	(0.0260)	(0.0342)	(0.0411)	(0.0283)	(0.0369)	(0.0454)
Country	Yes	Yes	Yes	Yes	Yes	Yes
Sector Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Thresholds						
μ_1	-1.372***	-1.326***	-1.920***	-1.524***	-1.464***	-2.065***
	(0.103)	(0.109)	(0.173)	(0.129)	(0.140)	(0.185)
μ_2	-1.173***	-1.138***	-1.705***	-0.647***	-0.594***	-1.162***
	(0.103)	(0.110)	(0.173)	(0.128)	(0.138)	(0.181)
μ_3	-0.670***	-0.641***	-1.186***	0.170	0.214	-0.315*
	(0.103)	(0.110)	(0.172)	(0.128)	(0.139)	(0.180)
μ_4	0.0335	0.0600	-0.471***	n.a.	n.a.	n.a.
	(0.103)	(0.110)	(0.172)			
Log Likelihood	-12821	-7778	-5008	-12535	-7613	-4882
Rho	n.a.	n.a.	n.a.	-0.513	-0.571	-0.323
/athrho	n.a.	n.a.	n.a.	-0.567***	-0.649***	-0.335
				(0.106)	(0.130)	(0.239)
Observations	10,027	6,199	3,828	9,960	6,148	3,812
Observation	n.a.	n.a.	n.a.	1,516	865	651
Observation	n.a.	n.a.	n.a.	8,444	5,283	3,161

Source: Authors' own elaboration

Notes: Estimated coefficients from ordered probit regression and ordered probit with sample selection. Robust standard errors in parentheses. * Coefficient is statistically significant at the 10 percent level; ** at the 5 percent level; *** at the 1 percent level; no asterisk means the coefficient is not different from zero with statistical significance. n.a. = not applicable.

Table 6. Determinants of Innovation

Variables	Product Innovation				Process Innovation			
	Probit		Bivariate Probit		Probit		Bivariate Probit	
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
Broadband Adoption	0.135***	-0.008	0.214***	0.064	0.128***	-0.027	0.255***	0.094**
	(0.020)	(0.030)	(0.036)	(0.044)	(0.021)	(0.031)	(0.039)	(0.047)
Internet Use for Purchases	n.a.	0.018	n.a.	0.016	n.a.	0.022	n.a.	0.019
		(0.020)		(0.019)		(0.020)		(0.020)
Internet Use to Deliver Services	n.a.	0.015	n.a.	0.013	n.a.	0.042**	n.a.	0.038*
		(0.020)		(0.020)		(0.021)		(0.020)
Internet Use for Research	n.a.	0.116***	n.a.	0.112***	n.a.	0.110***	n.a.	0.105***
		(0.020)		(0.020)		(0.021)		(0.021)
Internet for Purchases + Deliver Services + Research	n.a.	0.059**	n.a.	0.060**	n.a.	0.046*	n.a.	0.048*
		(0.025)		(0.024)		(0.025)		(0.025)
Micro Firm	-0.101***	-0.092***	-0.078***	-0.073**	-0.074***	-0.065**	-0.040	-0.035
	(0.027)	(0.027)	(0.028)	(0.028)	(0.028)	(0.028)	(0.029)	(0.029)
Small Firm	-0.045*	-0.042*	-0,038	-0.037	-0.076***	-0.074***	-0.066***	-0.065***
	(0.024)	(0.023)	(0.023)	(0.023)	(0.024)	(0.024)	(0.023)	(0.023)
Medium Firm	-0.044**	-0.045**	-0.043*	-0.044**	-0.073***	-0.074***	-0.072***	-0.073***
	(0.022)	(0.022)	(0.022)	(0.022)	(0.023)	(0.022)	(0.022)	(0.022)
Human Capital	0.001***	0.001**	0.001**	0.001**	0.001***	0.001***	0.001***	0.001**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Age of Firm	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
FDI	-0.003	0.007	-0.002	0.008	-0.038*	-0.029	-0.035*	-0.026
	(0.021)	(0.020)	(0.020)	(0.020)	(0.021)	(0.021)	(0.020)	(0.020)
Exporter	0.040**	0.033**	0.036**	0.030*	0.035**	0.029*	0.028*	0.022
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
Investment	0.132***	0.122***	0.129***	0.120***	0.194***	0.185***	0.187***	0.179***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Capital City	0.004	0.008	0.001	0.006	-0.010	-0.007	-0.015	-0.011
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	-3598,31	-3536,53	-4929,68	-4868,86	-3687,52	-3629,64	-5017,95	-4961,54
Rho	n.a.	n.a.	-0.170**	-0.145**	n.a.	n.a.	-0.269***	-0.242***
			(0.067)	(0.067)			(0.071)	(0.072)
/athrho	n.a.	n.a.	-0.172**	-0.146**	n.a.	n.a.	-0.276***	-0.247***
			(0.069)	(0.069)			(0.076)	(0.077)
Observations	5893	5893	5930	5930	5889	5889	5926	5926

Source: Author's own elaboration

Notes: Estimated average marginal effects; Delta-Method standard errors in parentheses; * Coefficient is statistically significant at the 10 percent level; ** at the 5 percent level; *** at the 1 percent level; no asterisk means the coefficient is not different from zero with statistical significance. n.a. = not applicable.

Table 7. Determinants of Productivity

Variables	OLS Estimations		2SLS Estimations	
	(1)	*(2)*	*(3)*	*(4)*
Broadband Adoption	0.314*** (0.047)	0.333*** (0.072)	0.546*** (0.113)	0.963*** (0.293)
Internet Use for Purchases	n.a.	0.038 (0.045)	n.a.	-0.152 (0.097)
Internet Use to Deliver Services	n.a.	-0.049 (0.045)	n.a.	-0.256** (0.104)
Internet Use for Research	n.a.	-0.052 (0.047)	n.a.	-0.307** (0.124)
Internet for Purchases + Deliver Services + Research	n.a.	0.071 (0.055)	n.a.	0.335** (0.131)
Log(Capital per worker)	0.191*** (0.011)	0.191*** (0.011)	0.190*** (0.011)	0.190*** (0.011)
Investment	0.139*** (0.029)	0.137*** (0.029)	0.128*** (0.029)	0.131*** (0.029)
Innovation	0.011 (0.032)	0.008 (0.033)	-0.004 (0.032)	0.008 (0.032)
Micro Firm	-0.493*** (0.059)	-0.483*** (0.059)	-0.441*** (0.062)	-0.428*** (0.064)
Small Firm	-0.331*** (0.050)	-0.328*** (0.050)	-0.319*** (0.050)	-0.310*** (0.050)
Medium Firm	-0.083* (0.047)	-0.084* (0.047)	-0.084* (0.046)	-0.079* (0.046)
Human Capital	0.007*** (0.001)	0.007*** (0.001)	0.007*** (0.001)	0.007*** (0.001)
Age of Firm	0.001* (0.001)	0.001 (0.001)	0.001 (0.001)	0.001 (0.001)
FDI	0.293*** (0.050)	0.295*** (0.050)	0.300*** (0.049)	0.294*** (0.049)
Exporter	0.219*** (0.034)	0.218*** (0.034)	0.209*** (0.034)	0.205*** (0.034)
Capital City	0.033 (0.030)	0.036 (0.031)	0.024 (0.030)	0.024 (0.031)
Constant	9.117*** (0.166)	9.108*** (0.166)	8.922*** (0.185)	8.818*** (0.209)
Country dummies	Yes	Yes	Yes	Yes
Sector dummies	Yes	Yes	Yes	Yes
R^2	0.461	0.462	0.458	0.450
Observations	4200	4200	4197	4197

Source: Author's own elaboration.

Notes: Estimated coefficients from the regressions; Controls for sector and country fixed effects; Robust standard errors in parentheses; * Coefficient is statistically significant at the 10 percent level; ** at the 5 percent level; *** at the 1 percent level; no asterisk means the coefficient is not different from zero with statistical significance. n.a. = not applicable.