Research Report

What Are the Drivers of ICT Diffusion? Evidence from Latin American Firms

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Abstract

It is generally recognized that information and communication technologies (ICTs) have radically changed how modern business is conducted, benefiting 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 and the Caribbean (LAC) is scarce and fragmented. Our article contributes to filling this gap by identifying the drivers of ICT diffusion in LAC firms. We find evidence of the presence of both epidemic and rank effects, where larger, older, skill-intensive, and exporter and urban firms are more likely to adopt ICTs. However, once adopted, size and location lose importance. The availability of novel empirical evidence specific to the LAC region offers useful insights to policymakers for the design and implementation of initiatives aimed at fostering productivity by increasing ICT adoption and intensive use.

Keywords: ICT, technology diffusion, Latin America

The Latin America and the Caribbean (LAC) region has shown low economic growth rates during the last 30 years, failing not only to catch up with developed countries, but even to keep pace with other emerging economies. Various macroeconomic analyses provide clear evidence that this disappointing performance has been mainly due to slow productivity growth (Crespi, Fernández-Arias, & Stein, 2014; Daude & Fernández-Arias, 2010; Pagés, 2010).

Over the last decades, economic literature has progressively recognized the link between information and communication technologies (ICTs) diffusion and productivity growth acceleration, both at the macro level (Jorgenson, 2001; Oliner & Sichel, 1994, 2002) and at the firm level (Brynjolfsson & Hitt, 2000, 2003). In fact, ICT adoption can improve business performance in several ways: ICTs speed up communication and information processing, decrease internal coordination costs, and facilitate decision making (Arvanitis & Loukis, 2009; Atrostic, Boegh-Nielsen, Motohashi, & Nguyen, 2004; Cardona, Kretschmer, & Strobel, 2013; Gilchrist, Gurbaxani, & 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 reducing inventory. Moreover, the possibility of developing better communication channels with suppliers, clients, knowledge providers, and competitors may increase innovation capacity.

As a result, fostering the adoption and intensive use of ICTs constitutes an opportunity to increase productivity in the region. In that sense, LAC countries face not only the challenge of closing the digital divide, but also of introducing advanced digital technologies through the value chains of its economies. According to

To cite this article: Grazzi, M., & Jung, J. (2019). What are the drivers of ICT diffusion? Evidence from Latin American firms. *Information Technologies & International Development, 15,* 34–48.

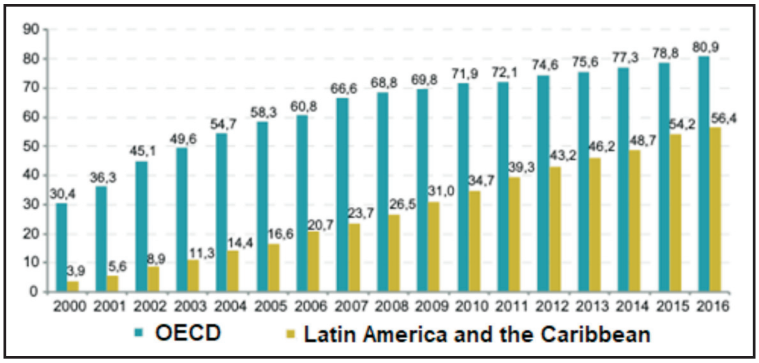

Figure 1. Internet users for every 100 inhabitants.

Source: Rojas & Poveda (2018)

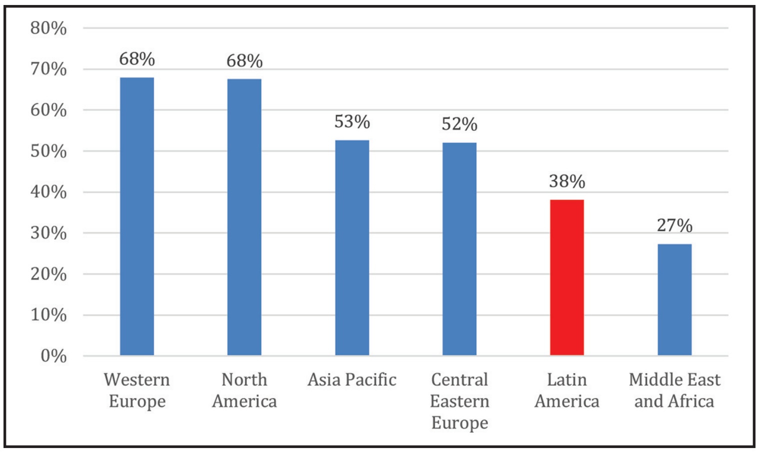

Figure 2. Expected growth in network devices and connections per person (2016–2021).

Source: CISCO VNI Data (https://www.cisco.com/c/m/en_us/solutions/service-provider/vni-forecast-highlights.html#)

Cadena, Remes, Grosman, and de Oliveira (2017), if Latin American countries are unable to increase productivity through the introduction of digitalization, the economic growth of the next 15 years will be 40–50% lower than that of the previous 15 years. To achieve those objectives, the digitalization of the LAC economy should be a top priority of the region's public policy agenda.

The LAC region has made important advances in closing the digital divide in recent years. As Figure 1 suggests, the gap between LAC and the most advanced countries in terms of Internet use in society has narrowed considerably since the beginning of the 2000s. However, the diffusion and use of ICTs at LAC firms are still relatively low. In fact, in the midterm, new divides threaten to arise, especially regarding most advanced technologies such as the Internet of Things (IoT), Big Data, and Artificial Intelligence, among others. As reported in Figure 2, CISCO forecasts[1] for 2021 a considerable increase in the gap between the number of connected devices per capita in Latin America and most advanced regions in the world such as North America and Western Europe. This worrisome scenario requires active public policies so as to accelerate ICT introduction and intensive use by LAC firms.

Therefore, a better understanding of the ICT diffusion dynamics is central to designing effective public policies that promote ICT adoption and increase firm innovation and productivity. Nevertheless, the bulk of the literature on ICT adoption has focused on developed countries, while evidence from emerging regions is still scarce and dispersed. As for the Latin American region, Waters (2017) recently provided an important contribution, by analyzing the determinants of initial adoption and subsequent intensification. This article helps to fill the knowledge gap by taking an alternative empirical approach to analyze the determinants of *interfirm* and *intrafirm* adoption in LAC, taking into account endogeneity and sample-election issues, considering sectoral heterogeneity, and offering useful insights to policymakers. This empirical approach adds robustness to our results and provides us further insights compared to most studies that have been performed to date.

The balance of this article is organized as follows. In the coming section we describe the theoretical framework, and in the next section the database is presented. Following that we describe the empirical model,

1. *https://www.cisco.com/c/m/en_us/solutions/service-provider/vni-forecast-highlights.html#*

discussing the relevant literature on determinants of ICT adoption. In the final section we discuss the results. We conclude with some policy implications.

Theoretical Framework

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 submodels: epidemic, rank (probit), stock, and order.

Early research introduced *epidemic* models based on the concept that a technology's diffusion depends on information about its availability (Mansfield, 1963). These models predict that the diffusion of new technology gradually increases over time, as adoption costs and risks decline based on learning effects among firms. The process resembles the spread of epidemics: Early adopters disseminate information, then other firms adopt the technology and release further information, and so on until reaching the saturation point. While epidemic models are traditionally based on information spillovers from users to non-users, for ICTs another dimension is relevant: network effects. In fact, the gains that derive from ICT adoption—as well as the opportunity costs of non-adoption—increase with the number of technology users, causing a snowball effect.

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

Finally, two game theory approaches model the returns on adoption, depending on the number of previous adopters and the order of adoption. *Stock* models are based on the assumption that the benefit of 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 unprofitable. On the other hand, *order* models reflect the advantages of early adopters, assuming that returns on adoption depend on a firm's position in the order of adoption because of advantages such as obtaining better skilled labor or geographic locations.

It is important to stress that even if most of the literature has focused on the demand side, technology diffusion dynamics are the result of the interaction between demand and supply-side factors. The models usually assume declining prices over time, but do not relate this reduction to supply-side forces. Moreover—and surprisingly—empirical research has mainly focused on *interfirm* diffusion (a firm's access to a new technology) and has neglected *intrafirm* diffusion (the extent of technology use in the firm). In this article, in line with recent literature, we empirically test the validity of the rank and epidemic[2] models in LAC firms, focusing both on inter- and intrafirm ICT diffusion.

Dataset and Variables

The data for the empirical analysis come from the World Bank Enterprise Surveys (WBES) database, which provides representative samples of the population of private-sector firms in the countries covered. The surveys cover a broad range of topics relevant to business, including, among others, innovation, ICTs, access to finance, corruption, infrastructure, crime, competition, and performance measures. The WBES are answered through face-to-face interviews with top managers and business owners. Typically, 1,200–1,800 interviews are conducted in larger economies, 360 interviews are conducted in medium-sized economies, and for smaller economies 150 interviews take place. Manufacturing and services are the primary business sectors of interest for the survey. The *survey population* is consistently defined in all countries as nonagricultural, non-extracting, formal, privately owned firms (Grazzi, Pietrobelli, & Szirmai, 2016). Formal (registered) companies with five or more employees are targeted for interview. Firms with 100% government or state ownership are ineligible to participate. In each country, businesses in the cities or regions of major economic activity are interviewed.

Since 2002 the World Bank has been collecting these data from over 155,000 companies in 148

2. We could not test the stock and order models due to the lack of panel data.

Table 1. ICT Variables.

Variable	Description
Broadband	Dummy variable if the firm has a high-speed Internet connection on its premises
Website	Dummy variable if the firm uses its own website
Internet use for purchases	Dummy variable if the firm uses its Internet connection to make purchases
Internet use for delivering services	Dummy variable if the firm uses its Internet connection to deliver client services
Internet use for research	Dummy variable if the firm uses its Internet connection to research and develop ideas on new products and services
Broadband intensity (scale)	Ordinal scale taking values 0, 1, 2, 3, and 4, depending on broadband adoption and the quantity of Internet uses performed by the firm

Source: Authors' own compilations.

economies. However, it is worth mentioning that information is not regularly available for all countries. While the WBES have been increasingly intending to produce panel data, limitations in availability exist. In Latin America for instance, surveys were mainly conducted in two waves, in 2006 and 2010, and while there are some firms that were surveyed in both years (forming a panel), critical information is still missing from the first wave. Unfortunately, this is the case for most ICT-related data, as most questions were introduced only in the 2010 round and not in all the surveyed countries.[3]

Therefore, after data cleaning, we obtained for our analysis a 2010 cross-section dataset of 10,477 enterprises from 19 Latin American and Caribbean countries,[4] where Mexico (13.7%), Argentina (9.6%), and Chile (8.6%) were the most-represented countries. The resulting sample includes enterprises of various sizes,[5] both from the manufacturing and service sectors.

Table 1 summarizes the description for the ICT-related variables available in the dataset, according to the specific question from the survey questionnaire. *Broadband* is a dummy variable which shows if a firm has adopted high-speed Internet connection. Therefore, this definition excludes the older and slower dial-up connections, which seem to be unsuitable for intensive uses in the period under analysis. On the other hand, we also measured ICT adoption with a website variable available in the dataset.

Additionally, we extend the analysis by considering not only broadband adoption, but also the degree of exploitation of its potential. This was measured through a series of Internet uses: (1) making purchases, (2) delivering services, and (3) researching or developing ideas for new products and services. To measure intrafirm diffusion, we have built an indicator related to the availability of broadband and the number of Internet activities performed by a firm. Then, our broadband intensity variable is an indicator using values 0, 1, 2, 3, and 4.

Table 2 summarizes the explanatory variables. As for rank effects, we first consider the size of the firms, grouping them into four categories: micro (≤10 employees), small (11–50 employees), medium (51–250), and large (≥251). Size is generally considered relevant to the adoption of new technologies. Given that larger firms have fewer financial constraints and are usually less risk averse, presumably they are in a better position to withstand the costs and risks associated with new technologies. Empirical evidence generally supports this hypothesis (Fabiani, Schivardi, & Trento, 2005; Giunta & Trivieri, 2007; Haller & Siedschlag, 2011; Teo & Tan, 1998).[6] We use large firms as our reference group.

3. For example, the last Brazil survey included ICTs in the questionnaire that applied to the service sector, but not in the one that applied to the manufacturing sector.

4. Argentina, Bolivia, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, México, Nicaragua, Panamá, Paraguay, Perú, Trinidad and Tobago, Uruguay, and Venezuela.

5. 11% of the observations are large firms (≥251 employees), 28% medium firms (50–250 employees), 39% small firms (11–50 employees), and 22% micro firms (≤10 employees).

6. Some studies (e.g., Lefebvre, Lefebvre, Elia, & Boek, 2005; Love, Irani, Standing, Lin, & Burn, 2005) have found a weak or insignificant correlation between size and ICT adoption.

Table 2. Explanatory Variables.

Effect	Variable	Description
Rank effects	Size	Dummy variables: micro (≤10 employees); small (11–50 employees); medium (51–250 employees); large (baseline scenario, ≥251 employees)
	Age	Age of the firm (years)
	Human capital	Percentage of workers with at least a Bachelor's degree
	Export activity	Dummy variable if 10% or more of the firm's sales are exported
	FDI	Dummy variable if at least 10% of the capital is foreign owned
Location effects	Capital city	Dummy variable if the firm is located in a capital or a city with more than 1 million inhabitants
Epidemic effects	Epidemic broadband	Percentage of other firms that have adopted broadband in the same country and sector
	Epidemic website	Percentage of other firms that have a website in the same country and sector
Country effects	Country	Country dummy variables
Sector effects	Sector	3-digit sector dummy variables

Source: Authors' own compilations.

We then consider the firm's age as a proxy for its technological experience and we look at the percentage of workers with at least a Bachelor's degree as a proxy for human capital. The relationship between a skilled workforce and ICT adoption is clear in the literature,[7] which shows that a more educated workforce facilitates the early adoption of technologies (Chun, 2003) and that the demand for skilled workers increases with the use of new technologies (Bartel & Sicherman, 1999). However, the role of firm age is not theoretically straightforward. In fact, on one hand, older firms are better equipped to assess the risks and benefits of introducing new technologies. On the other hand, younger enterprises are believed to be more flexible in dealing with the organizational changes that come with ICT adoption. The empirical evidence is inconclusive, in general, finding either a nonsignificant (Bayo-Moriones & Lera-Lopez, 2007; Giunta & Trivieri, 2007) or negative impact (Gambardella & Torrisi, 2001; Haller & Siedschlag, 2011) of age on ICT diffusion.

The next two variables we consider are exposure to international competition (export activity) and the need to be ICT early adopters to maintain fluid communication with foreign partners (foreign direct investment, or FDI). Export activity is a dummy variable, taking the value of 1 if at least 10% of the firm's sales are exported. FDI is also a dummy variable, taking the value of 1 if at least 10% of the firm's capital is foreign owned. In general, empirical evidence shows that firms that engage in foreign trade are more likely to adopt new technologies (Haller & Siedschlag, 2011; Hollenstein, 2004; Lucchetti & Sterlacchini, 2004), and that those foreign-owned firms tend to be early adopters, contributing to technology diffusion in the country where they operate (Keller, 2004; Narula & Zanfei, 2005).

Capital city, a dummy variable that takes the value of 1 if the firm is located in a capital or a city of over 1 million inhabitants, controls for location effects. The empirical literature demonstrates the influence on ICT adoption of an urban or densely populated location. Many arguments support this hypothesis such as the proximity of suppliers, technology prices, and the availability of a qualified labor force (Galliano, Roux, & Filippi, 2001; Karlsson, 1995).

To account for epidemic effects, we calculate the percentage of other firms that have 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 that existing technology adopters have positive spillover effects on firms considering adoption. In other words, firms operating in more digitally advanced countries and sectors

7. See, for example, Arvanitis (2005), Bresnahan, Brynjolfsson, and Hitt (2002), and Fabiani et al. (2005).

may face reduced costs and increased benefits. Finally, in all estimations we include country and three-digit sector dummy variables to control for unobserved industry and region-specific effects.

In Table 3, the main descriptive statistics of the resulting dataset are reported. As can be seen, there is a high level of broadband adoption (85%); however, figures are considerably reduced when we further analyze the data regarding website (63%). As for the remaining uses, nearly 67% of the firms declare use of the Internet for research activities, while the use for purchases and service delivery, on average, reach 63% and 61% positive replies, respectively.

Empirical Specification

With the objective of identifying determinants of interfirm diffusion, we estimate the following equation to model the probability that a firm will adopt ICT:

$$\Pr(\textit{ICT Adoption} = 1) = F(\beta_0 + \beta_1 \textit{ Rank Effects} + \beta_2 \textit{ Location Effects} + \beta_3 \textit{ Epidemic Effects} + \beta_4 \textit{ Country Effects} + \beta_5 \textit{ Sector Effects})$$

To measure interfirm ICT adoption, we consider both broadband and website indicators. Then, we estimate two equations in which broadband and website are the dependent variables. As for rank, location, epidemic, country, and sector effects, we consider the explanatory variables described in Table 2.

To estimate the two adoption equations, we use a sequential approach. First, we apply a *probit model,* which is a common econometric approach that uses maximum likelihood estimation. This approach is not always fully efficient because it does not consider the correlation between firm choices in adopting broadband and having a website. Therefore, to consider this possible correlation and to improve the robustness of our estimates, we complement the probit analysis with a bivariate probit (biprobit) model (Greene, 2003).

The basic model of intrafirm diffusion does not differ substantially from the interfirm diffusion, given that the penetration level is supposed to depend on both epidemic and rank effects. The first major difference relates to the form of the dependent variables. In this case, we use the broadband intensity variable described in Table 1, an indicator using the values 0, 1, 2, 3, and 4. In this case, we use an ordered probit model, which is appropriate when the dependent variables are measured on an ordinal scale.

However, this approach fails to account for the correlation between broadband adoption and intensity of Internet use. In fact, broadband adoption entirely determines the extent of use, selecting firms that have the capabilities to perform activities. To disentangle the determinants of inter- and intrafirm 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 & Van Praag, 1981), specifying an ordered probit with sample selection, wherein the first stage equation is the broadband interfirm diffusion equation, including both location and epidemic effects. The possibility of controlling for sample selection is relevant to add robustness to our results and marks an improvement from most empirical approaches used by similar studies.

Results

In this section results for both inter- and intrafirm determinants of diffusion are presented. We show the marginal effects resulting from our estimations with probit in Table 4. Columns 1 and 2 present results for broadband adoption, while columns 3 and 4 refer to having a website. Columns 1 and 3 correspond to the basic model, while columns 2 and 4 add the capital city and epidemic variables as regressors.

We present the biprobit estimates in Table 5, with the basic estimates displayed on the left and those with capital city and epidemic variables included on the right. Additionally, to check for sectoral differences, we split the sample between manufacturing and services. In Table 6, we report the marginal effects from these disaggregated biprobit estimations.

Overall, the results appear robust for all the specifications and are generally in line with the findings of previous studies. The smaller the firm, the less likely it is to have a broadband connection or a functioning website, confirming the existence of barriers to the adoption of new technologies by small and medium-sized

Table 3. Descriptive Statistics.

Variables	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**	**Observations**
Broadband	0.848	0.359	0	1	10,440
Website	0.630	0.483	0	1	10,460
Internet use for purchases	0.626	0.484	0	1	10,440
Internet use to deliver services	0.605	0.489	0	1	10,440
Internet use for research	0.674	0.469	0	1	10,440
Broadband intensity (scale)	2.752	1.426	0	4	10,440
Micro firm	0.219	0.414	0	1	10,440
Small firm	0.394	0.489	0	1	10,440
Medium firm	0.277	0.448	0	1	10,440
Human capital	16.864	21.635	0	100	10,165
Age	25.898	20.036	1	185	10,330
FDI	0.129	0.336	0	1	10,477
Exporter	0.162	0.369	0	1	10,477
Capital city	0.497	0.500	0	1	10,477

Source: Authors' own calculations.

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

	Broadband Connection		**Website**	
Variables	**(1)**	**(2)**	**(3)**	**(4)**
Micro firm	−0.2718*** (0.0182)	−0.2666*** (0.0182)	−0.4782*** (0.0198)	−0.4697*** (0.0198)
Small firm	−0.1433*** (0.0181)	−0.1403*** (0.0180)	−0.3084*** (0.0195)	−0.3040*** (0.0194)
Medium firm	−0.0609*** (0.0188)	−0.0588*** (0.0186)	−0.1172*** (0.0203)	−0.1155*** (0.0203)
Human capital	0.0022*** (0.0002)	0.0022*** (0.0002)	0.0023*** (0.0002)	0.0023*** (0.0002)
Age	0.0007*** (0.0002)	0.0007*** (0.0002)	0.0014*** (0.0002)	0.0014*** (0.0002)
FDI	0.0138 (0.0122)	0.0126 (0.0122)	0.0612*** (0.0155)	0.0594*** (0.0155)
Exporter	0.0868*** (0.0146)	0.0876*** (0.0145)	0.1115*** (0.0148)	0.1120*** (0.0148)
Capital city	n.a.	0.0233*** (0.0070)	n.a.	0.0458*** (0.0094)
Epidemic (broadband)	n.a.	0.1193*** (0.0326)	n.a.	n.a.
Epidemic (website)	n.a.	n.a.	n.a.	0.1517*** (0.0365)
Country dummies	Yes	Yes	Yes	Yes
Sector dummies	Yes	Yes	Yes	Yes
Log likelihood	−3,010	−2,999	−4,880	−4,859
Pseudo R-squared	0.278	0.281	0.232	0.236
Observations	9,583	9,583	9,583	9,583

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

enterprises (SMEs) in Latin America. Although the full analysis of those barriers is beyond the scope of this study, it seems plausible that they relate to both a lack of resources and the inability to assess the risks of investing in digital technologies. On the other hand, the level of human capital appears to be an important adoption determinant, confirming the relevance of having a skilled workforce to increase a firm's capacity to absorb technology. This suggests that firms with an unskilled workforce will face important difficulties in the near future, as they will struggle to adopt digital technologies. The fact that enterprises will need to incorporate IoT, Big Data, and other advances to remain competitive in the coming years will only increase the relevance of a skilled workforce. Interestingly, and contrary to the findings reported in Waters (2017), in our estimations firm age shows a positive and significant—although small—coefficient. This result seems to demonstrate that previous technological experience is more important for ICT adoption by LAC firms than flexibility to organizational changes. These results hold for the entire sample, as well as for both the manufacturing and services subsamples.

In general, exposure to competition in foreign markets, as measured by the exporter dummy, positively impacts the probability a firm will adopt ICTs, with the exception of broadband adoption in the case of

Table 5. Determinants of Broadband Connection and Using Firm Website: Biprobit Estimations.

Variables	Basic Model		Augmented Model	
	Broadband (1)	**Website (2)**	**Broadband (3)**	**Website (4)**
Micro firm	−0.2656*** (0.0175)	−0.4708*** (0.0192)	−0.2605*** (0.0175)	−0.4625*** (0.0192)
Small firm	−0.1409*** (0.0174)	−0.3041*** (0.0189)	−0.1381*** (0.0174)	−0.2998*** (0.0188)
Medium firm	−0.0621*** (0.0181)	−0.1161*** (0.0197)	−0.0598*** (0.0180)	−0.1143*** (0.0196)
Human capital	0.0021*** (0.0002)	0.0024*** (0.0002)	0.0020*** (0.0002)	0.0024*** (0.0002)
Age	0.0007*** (0.0002)	0.0013*** (0.0002)	0.0007*** (0.0002)	0.0013*** (0.0002)
FDI	0.0121 (0.0117)	0.0557*** (0.0150)	0.0109 (0.0117)	0.0538*** (0.0150)
Exporter	0.0818*** (0.0141)	0.1057*** (0.0141)	0.0822*** (0.0140)	0.1064*** (0.0141)
Capital city	n.a.	n.a.	0.0226*** (0.0068)	0.0454*** (0.0092)
Epidemic (broadband)	n.a.	n.a.	0.1073*** (0.0303)	n.a.
Epidemic (website)	n.a.	n.a.	n.a.	0.1487*** (0.0341)
Country dummies	Yes	Yes	Yes	Yes
Sector dummies	Yes	Yes	Yes	Yes
Log likelihood	−7,825		−7,796	
Rho	0.4448 (0.0206)		0.4435 (0.0207)	
/athrho	0.4779*** (0.0257)		0.4766*** (0.0257)	
Observations	9,950		9,950	

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

exporters in the services sector. On the contrary, we find no significant effect of foreign ownership on broadband connection, although it seems to be important for having a website, especially in the services sector.

Finally, the estimates show the key role that location and epidemic effects 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 greater probability of adopting them. However, when the sample is split by sector, the epidemic variable loses significance for manufacturing firms, suggesting that epidemic effects can be particularly important for firms in the services sector. Moreover, the firms located in a capital or a city with more than 1 million inhabitants are, in general, more likely to both have a broadband connection and a website.[8] This is

8. *With the exception of the biprobit estimation in the services sector with broadband as an independent variable.*

Table 6. Determinants of Broadband Connection and Using Firm Website: Biprobit Estimations by Sector.

	Manufacturing		Services	
Variables	**Broadband (1)**	**Website (2)**	**Broadband (3)**	**Website (4)**
Micro firm	−0.2545*** (0.0229)	−0.4702*** (0.0247)	−0.2673*** (0.0271)	−0.4496*** (0.0310)
Small firm	−0.1447*** (0.0227)	−0.3021*** (0.0240)	−0.1233*** (0.0269)	−0.2990*** (0.0307)
Medium firm	−0.0490** (0.0240)	−0.1264*** (0.0246)	−0.0699** (0.0274)	−0.0928*** (0.0325)
Human capital	0.0017*** (0.0003)	0.0030*** (0.0004)	0.0022*** (0.0003)	0.0019*** (0.0003)
Age	0.0005** (0.0002)	0.0015*** (0.0003)	0.0009*** (0.0003)	0.0008** (0.0004)
FDI	0.0047 (0.0166)	0.0141 (0.0199)	0.0225 (0.0171)	0.1047*** (0.0225)
Exporter	0.0871*** (0.0151)	0.0957*** (0.0150)	0.0446 (0.0332)	0.1637*** (0.0408)
Capital city	0.0278*** (0.0087)	0.0336*** (0.0119)	0.0161 (0.0110)	0.0647*** (0.0148)
Epidemic (broadband)	0.0148 (0.0364)	n.a.	0.1586*** (0.0604)	n.a.
Epidemic (website)	n.a.	0.0544 (0.0429)	n.a.	0.1576** (0.0612)
Country dummies	Yes	Yes	Yes	Yes
Sector dummies	Yes	Yes	Yes	Yes
Log likelihood	−4,645		−3,092	
Rho	0.407		0.510	
Observations	6,147		3,803	

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

another important difference with Waters (2017), who was unable to find any incidence of location in Internet adoption. In our case, the presence of this location effect may reflect lower technology costs, higher availability of trained human capital, and potential partners (i.e., suppliers and clients) with a higher level of connectivity. If we adopt an extended concept of epidemic effects, not limited to firms operating in the same sector, this result complements the importance of the technological assimilation level of the environment in which a firm is operating in order to determine its pace of adoption.

Table 7 shows the results related to intrafirm diffusion, by reporting the estimated coefficients resulting from the ordered probit model and the ordered probit with sample selection, for the whole sample and disaggregated by sector. In general, the estimates show a similar pattern to those for interfirm diffusion. Human capital, firm age, and being an exporter 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

Table 7. Determinants of Broadband Intensity of Use: Ordered Probit and Ordered Probit with Sample Selection Estimates.

	Ordered Probit			Ordered Probit with Sample Selection		
Variables	**Whole Sample**	**Manufacturing**	**Services**	**Whole Sample**	**Manufacturing**	**Services**
Micro firm	−0.8623***	−0.8576***	−0.8756***	−0.1545***	20.1183	−0.2527**
	(0.0476)	(0.0617)	(0.0773)	(0.0596)	(0.0744)	(0.1212)
Small firm	−0.3081***	−0.2928***	−0.3312***	−0.1101**	−0.0565	−0.1993**
	(0.0424)	(0.0543)	(0.0699)	(0.0470)	(0.0600)	(0.0818)
Medium firm	−0.0683	−0.0081	−0.1667**	−0.0368	0.0005	−0.1076
	(0.0418)	(0.0523)	(0.0703)	(0.0456)	(0.0570)	(0.0791)
Human capital	0.0069***	0.0067***	0.0071***	0.0021***	0.0031***	0.0018
	(0.0007)	(0.0010)	(0.0009)	(0.0007)	(0.0010)	(0.0011)
Age	0.0026***	0.0021***	0.0035***	0.0016**	0.0016*	0.0018
	(0.0006)	(0.0008)	(0.0011)	(0.0007)	(0.0008)	(0.0012)
FDI	−0.0649*	−0.1146**	0.0102	−0.0771*	−0.1154**	−0.0194
	(0.0374)	(0.0498)	(0.0570)	(0.0394)	(0.0513)	(0.0621)
Exporter	0.2291***	0.2322***	0.2115**	0.1069***	0.0872**	0.1999**
	(0.0356)	(0.0396)	(0.0913)	(0.0375)	(0.0421)	(0.0947)
Capital city	0.0377	0.0172	0.0644	−0.0385	−0.0852**	0.0307
	(0.0261)	(0.0343)	(0.0412)	(0.0283)	(0.0369)	(0.0455)
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes
Thresholds						
	−1.3715***	−1.3274***	−1.9148***	−1.5240***	−1.4638***	−2.0654***
	(0.1029)	(0.1096)	(0.1730)	(0.1291)	(0.1396)	(0.1851)
	−1.1731***	−1.1381***	−1.7011***	−0.6470***	−0.5941***	−1.1625***
	(0.1034)	(0.1105)	(0.1730)	(0.1276)	(0.1376)	(0.1807)
	−0.6678***	−0.6387***	−1.1819***	0.1701	0.214	−0.3148*
	(0.1033)	(0.1104)	(0.1726)	(0.1283)	(0.1387)	(0.1800)
	0.0346	0.0607	−0.4672***	n.a	n.a	n.a
	(0.1032)	(0.1104)	(0.1721)			
Log likelihood	−12,736	−7,718	−4,984	−12,533	−7,613	−4,880
Rho	n.a.	n.a.	n.a.	−0.513	−0.571	−0.324
				(0.0783)	(0.0876)	(0.2138)
/athrho	n.a.	n.a.	n.a.	−0.5669***	−0.6488***	−0.3358
				(0.1063)	(0.1299)	(0.2388)
Observations	9,958	6,148	3,810	9,958	6,148	3,810
Observation censored	n.a.	n.a.	n.a.	1,514	865	649
Observation uncensored	n.a.	n.a.	n.a.	8,444	5,283	3,161

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% level, ** at the 5% level, *** at the 1% level; no asterisk means the coefficient is not different from zero with statistical significance.*
n.a. = not applicable.
Source: Authors' own calculations.

coefficient for medium firms is significant only for the services sector. Once we control for the sample selection, for manufacturing all the size coefficients become smaller and not significant; for services the coefficients also become smaller, but they lose significance only for medium firms. For manufacturing, size does not seem to matter for intensity of use once broadband is adopted. For services, the result seems to indicate a dimension threshold, above which size does not matter for intrafirm diffusion. Furthermore, we find no strong statistical evidence related to a capital city location, which suggests that location affects the decision to adopt broadband, but not how extensively it is used. Finally, there is some evidence of a negative correlation between foreign ownership and intrafirm diffusion, but only in the manufacturing sector. This result is stronger in the ordered probit with sample selection, which may relate to the fact that foreign investments in manufacturing in LAC are concentrated in low-value-added activities, while research and other skill-intensive activities are carried out in the headquarters. Therefore, ICTs seem to be especially important for communication with headquarters, but not for research and relationships with providers or clients, the activities used to build the intensity index.

Conclusions and Policy Implications

This article contributes to the empirical literature on technology diffusion, identifying determinants of ICT adoption in the context of LAC firms. This is a key topic for the LAC region, as it needs to accelerate the adoption and intensive use of the latest technologies (particularly IoT and Big Data) to increase its productivity levels.

We analyzed both interfirm and intrafirm diffusion patterns, finding that the ICT adoption behavior of LAC firms is characterized by a basic set of determinants, which is robust across the diverse model estimations and different variable specifications. We found evidence of the presence of both epidemic and rank effects, where larger, older, skill-intensive, and exporter and urban firms are more likely to adopt ICTs. However, once adopted, size and location lose importance.

The availability of novel empirical evidence specific to Latin America may offer useful insights to policymakers into the design and implementation of initiatives aimed at fostering productivity by increasing broadband connectivity. In fact, in recent years several countries have invested considerable resources into initiatives such as the *Plano Nacional de Banda Larga* in Brazil, or the *Vive Digital* plan in Colombia.

In particular, given the difficulties faced by smaller enterprises in adopting and intensively using digital technologies, public authorities should consider launching specific programs designed for SMEs to help those firms overcome the barriers currently inhibiting them. It is possible that those barriers relate to a lack of resources and an inability to assess the risks of investing in digital technologies, so public facilities under the form of targeted subsidies for most disadvantaged firms in order to stimulate ICT demand in specific segments can contribute to overcoming those restrictions. Likewise, regulation should not restrict telecom operators from offering a wide range of commercial plans, which may contribute to the availability of offers suited to the needs and economic capacity of disadvantaged sectors such as most SMEs.

On the other hand, given the relevance of location effects for Internet adoption, public policies must contribute to ensuring broadband coverage in small and remote areas. In this context, network deployments in broadband infrastructure by service providers are critical, it being essential that regulatory policies do not reduce investment incentives for carriers. Rather, they should reduce barriers and avoid cost increases linked by bureaucracy or other associated red-tape costs. On the other hand, in areas of low population density not reached by private investment, public intervention in the form of universalization policies may be crucial.

Some companies are limited in adopting and intensively using ICTs due to their lack of human capital. In general terms, the LAC region presents an important deficit of skilled workers with the ability to make the most of digital technologies. To give some insights on this divide, the number of Latin America graduates comes to approximately 145,000 engineers annually, while the United States, with half the population, doubles that figure, graduating 293,000 in 2012 (Katz, 2015). Public policies should contribute to overcome this limitation.

Beyond size, location, and human capital, it is clear that younger LAC firms face difficulties in adopting and intensively using ICTs. The reason may relate to the design of internal processes and organizational capital less prone to the adoption of digital technologies or to institutional reasons, given that in other regions the firm age was found to be irrelevant. In any case, more insights are needed as this is an important field for future research and for designing public intervention to overcome these difficulties.

All in all, while we were able to derive important contributions, there remain unresolved questions that require further research. In particular, a lack of data prevented us from finding out if the diffusion drivers related to the latest advances—such as IoT—differ from those regarding Internet and website adoption. These extensions may provide a deeper understanding of the ICT diffusion dynamics and the characteristics that effective public policies should possess. ■

Acknowledgments

This article was produced as part of the Inter-American Development Bank research project, Policies and Institutions for Productivity in Latin America and the Caribbean (RG-T1861). The opinions expressed in this article are those of the authors and do not necessarily reflect the views of the Inter-American Development Bank, its board of directors, or the countries they represent. A more extensive and earlier version of this article was included in the chapter "ICT, Innovation and Productivity: Evidence from Firms in Latin America and the Caribbean" (Grazzi & Jung, 2016) in *Firm Innovation and Productivity in Latin America and the Caribbean: The Engine of Economic Development* (Grazzi & Pietrobelli, 2016). The authors would like to thank Carlo Pietrobelli, Eddy Szirmai, and Sebastián Vergara for their helpful comments and discussion. Siobhan Pangerl and Leonardo Ortega provided excellent research assistance.

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