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CHAPTER 4

# Information and Communication Technologies, Innovation, and Productivity: Evidence from Firms in Latin America and the Caribbean

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Over recent 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 accelerating productivity growth and ICT diffusion in the context of growth accounting (Oliner and Sichel 1994, 2002; Jorgenson 2001).

At the firm level, ICT adoption can improve business performance in various ways: ICTs speed up communication and information processing, decrease internal coordination costs, and facilitate decision-making (Cardona et al. 2013; Arvanitis and Loukis 2009; Atrostic et al. 2004; Gilchrist et al.

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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.

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 of ICT adoption, but also the impact once adopted. Therefore, complementary investment in areas such as organizational change and human capital appear necessary both to increase absorptive capacity and to maximize 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, improve performance.

A complete understanding of these dynamics is central to designing 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 fragmented. This chapter aims to fill this knowledge gap by exploring the determinants of broadband adoption and assessing their relationship with innovation and productivity in Latin America and the Caribbean (LAC).

The rest of the chapter is organized as follows. First we describe the main patterns of diffusion of the internet in LAC and the data we use in our empirical analysis. Then we discuss determinants of ICT adoption and explore the relationship between broadband, innovation, and productivity. We review the relevant theoretical and empirical literature, specifying the empirical model employed and discussing the main results. Finally, we provide concluding remarks.

## Data and Main Patterns of Internet Diffusion in LAC

The diffusion and use of ICT is still relatively low in LAC. In fact, although ICTs have significantly increased in the region, there is still a notable divide between LAC and developed countries, especially in the most advanced technologies.[1] Using data from the International Telecommunications Union (ITU) for 2014, Fig. 4.1 displays an international comparison for fixed broadband penetration. Western Europe (EUR) and USA–Canada (US-

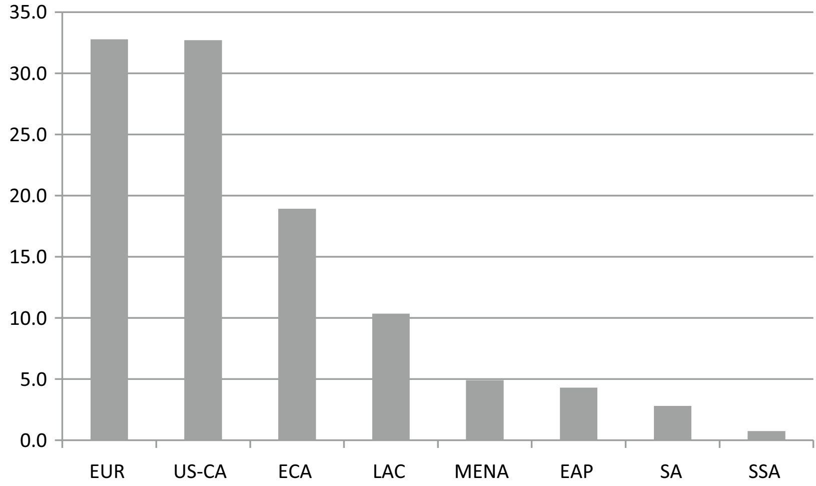


**Fig. 4.1** Fixed broadband subscriptions by region (2014)

*Source*: Authors' elaboration using data from the ITU

*Notes*: Simple average of available countries in each region. **EUR**: (*Western Europe*) Austria, Belgium, Croatia, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, Netherlands, Portugal, Spain, Sweden, United Kingdom, Norway, and Switzerland; **US-CA**: The United States and Canada; **ECA**: (*Eastern Europe and Central Asia*) Bosnia and Herzegovina, Bulgaria, Czech Republic, Estonia, Hungary, Kazakhstan, Kyrgyz Republic, Latvia, Lithuania, Moldova, Mongolia, Montenegro, Poland, Romania, Russia, Serbia, Slovak Republic, Slovenia, and Ukraine; **LAC**: 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, Saint Lucia, St. Kitts & Nevis, St. Vincent & the Grenadines, Suriname, Trinidad and Tobago, Uruguay, and Venezuela; **MENA**: *Middle East and North Africa*) Algeria, Djibouti, Egypt, Arab Republic, Jordan, Lebanon, Libya, Morocco, Syrian Arab Republic, Tunisia, and Yemen; **EAP**: (*East Asia and Pacific*) Indonesia, Lao PDR, Micronesia, Philippines, Samoa, Timor Leste, Tonga, Vanuatu, and Vietnam; **SA**: (*South Asia*) Afghanistan, Bangladesh, Bhutan, India, Iran, Maldives, Nepal, Pakistan, and Sri Lanka; **SSA**: (*Sub-Saharan Africa*) Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Chad, Comoros, Congo, Cote d'Ivoire, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Somalia, South Africa, South Sudan, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, and Zimbabwe

CA) appear at the top, with 32 connections per 100 people. Eastern Europe and Central Asia (ECA) and LAC are far behind, with 19 and 10 connections per 100 people, respectively. Middle East and North Africa (MENA), East Asia and the Pacific (EAP), South Asia (SA), and Sub-Saharan Africa (SSA) report 5, 4, 3, and 1 connections per 100 habitants, respectively.

With respect to ICT diffusion in firms, an international comparison is much more complicated because it requires precise and comparable data, which is 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, using face-to-face interviews with top managers, covering a broad range of topics relevant to business, including innovation, ICT, access to finance, corruption, infrastructure, crime, 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.[2]

For this reason, a comparison is possible only among those regions that have enough countries reporting data on ICT access. Fig. 4.2 shows the level of broadband diffusion, email use, and website availability for the surveyed firms, by region.

LAC emerges as the region among the developing countries with the highest level of ICT penetration, with almost 85% of its firms indicating that they have a high-speed internet connection, 90% using email to communicate with clients or suppliers,[3] and 60% having their own website. This analysis shows that, overall, ICT diffusion among firms in LAC appears generally to be higher than in other developing regions, though we are cautious in our assessment of these results. First, the WBES does not provide information about adopting and using more advanced ICTs, only basic technologies that firms in advanced economies take for granted, and thus the resulting picture could be too optimistic. Second, WBES data on ICT diffusion in firms are not always consistent with ITU data on diffusion in society, raising some concerns about data reliability. For example, Fig. 4.3 shows the correlation between the percentage of households with a fixed broadband connection (ITU data) and the percentage of firms with broadband on their premises (WBES data) in LAC. 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 a broadband connection, even lower than Nicaragua and Honduras.

Even considering these caveats, the WBES provide excellent observations to empirically study ICT dynamics in LAC firms because they are the first attempt to collect related data with the same questionnaire and sampling across all countries. After data cleaning, the analysis included in this chapter is based on a 2010 cross-section dataset of 10,477 enterprises from 19 LAC countries,[4] with Mexico (13.7%), Argentina (9.6%), and

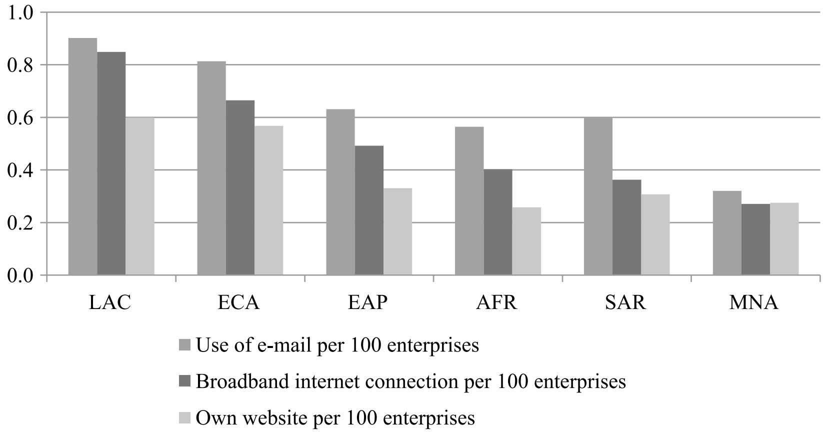


**Fig. 4.2** ICT diffusion in enterprises (2009–2010)

*Source*: Authors' elaboration based on WBES data

*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, Saint Lucia, St. Kitts & Nevis, St. Vincent & the Grenadines, Suriname, Trinidad and Tobago, Uruguay, and Venezuela; **ECA**: (*Eastern Europe and Central Asia*) 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, and Slovenia; **EAP**: (*East Asia and Pacific*) Fiji, Indonesia, Lao PDR, Micronesia, Philippines, Samoa, Timor Leste, Tonga, Vanuatu, and Vietnam; **AFR**: (*Africa*) Angola, Benin, Botswana, Burkina Faso, Cameroon, Cape Verde, Chad, Congo, Democratic Republic of the Congo, Eritrea, Gabon, Ivory Coast, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritius, Niger, Sierra Leone, and Togo

Chile (8.6%) being the most represented in terms of observations. The resulting sample includes enterprises of various sizes[5] from both the manufacturing and services sectors. In Table 4.1, we provide the sample's main descriptive statistics.

## ICT Adoption

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 sub-models: Epidemic, rank (probit), stock, and order.

**Table 4.1** Descriptive statistics

| *Variables* | *Mean* | *Standard deviation* | *Minimum* | *Maximum* | *Observations* |
|---|---|---|---|---|---|
| Broadband | 0.848 | 0.359 | 0 | 1 | 10,440 |
| E-mail | 0.904 | 0.295 | 0 | 1 | 10,462 |
| 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 |
| Internet for purchases, to deliver services, and for research | 0.429 | 0.495 | 0 | 1 | 10,440 |
| Broadband intensity (scale) | 2.752 | 1.426 | 0 | 4 | 10,440 |
| 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 | 10,440 |
| Small firm | 0.394 | 0.489 | 0 | 1 | 10,440 |
| Medium firm | 0.277 | 0.448 | 0 | 1 | 10,440 |
| Skilled human capital | 16.864 | 21.635 | 0 | 100 | 10,165 |
| Age of firm | 25.898 | 20.036 | 1 | 185 | 10,330 |
| Foreign direct investment (FDI) | 0.129 | 0.336 | 0 | 1 | 10,477 |
| Exporter | 0.162 | 0.369 | 0 | 1 | 10,477 |
| Investment | 0.555 | 0.497 | 0 | 1 | 10,415 |
| Capital city | 0.497 | 0.500 | 0 | 1 | 10,477 |

*Source*: Authors' elaboration based on WBES data.

Early research introduced epidemic models based on the concept that the diffusion of a technology 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 is similar to the spread of epidemics: early adopters disseminate information, then 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, for ICT another dimension is very relevant: network effects. In fact, the gains that derive from ICT adoption—as well as the opportunity costs of not adopting—increase with the number of users of the technology, causing a snowball effect.

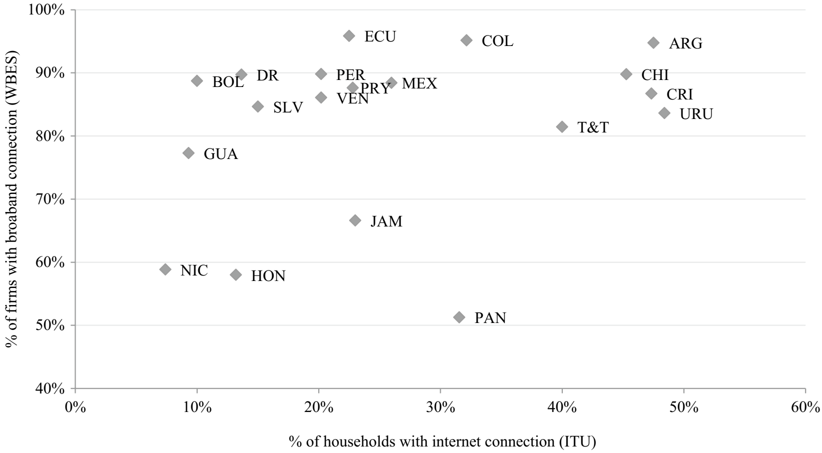


**Fig. 4.3** ICT diffusion in LAC (latest available year)
*Source*: Authors' elaboration based on ITU and WBES data

However, without considering firm heterogeneity, these models are not sufficient to explain fully 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 not profitable. On the other hand, order models reflect the advantages of early adopters, assuming that returns on adoption depend on the position of a firm 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 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 models usually assume declining 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.

### *Model Specification and Results*

In this chapter, in line with recent literature, we empirically test the validity of the rank and epidemic[6] models in LAC firms, focusing on inter- and intra-firm ICT diffusion. To identify determinants of inter-firm diffusion, we estimate the following equation to model the probability a firm will adopt ICT:

$$\begin{aligned}\Pr(\text{ICTADOPTION}=1)= \\ &\text{F}(\alpha+\ \beta_0 * \textit{RankEffects}+\beta_1 * \textit{LocationEffects} \\ &+\ \beta_2 * \text{EpidemicEffects}+\ \beta_3 * \text{CountryEffects} \\ &+\ \beta_4 * \text{SectorEffects})\end{aligned} \tag{4.1}$$

To measure inter-firm ICT adoption, we consider two dichotomic indicators: broadband, using the value 1 if a firm has a high-speed internet connection on its premises, and website, using the value 1 if a firm has its own website. Then, we estimate two equations where broadband and website are the dependent variables.

As for rank effects, we first consider the size of the firm, grouping them into four categories: micro (10 or less employees), small (11–50 employees), medium (51–250), and large (251 or more). Size is generally considered relevant to the adoption of new technologies. Given that larger firms have fewer financial constraints and are usually less risk adverse, supposedly they are in a better position to withstand the costs and risks associated with new technologies.[7] Empirical evidence generally supports this hypothesis (Teo and Tan 1998; Fabiani et al. 2005; Haller and Siedschlag 2011; Giunta and Trivieri 2007).[8] We use large firms as our reference group.

We then consider the firm's age as a proxy for its technological experience (age of firm), and we look at the percentage of workers with at least a bachelor's degree as a proxy for human capital (skilled human capital). The relationship between a skilled workforce and ICT adoption is relatively clear in the literature,[9] 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 and Sicherman 1999); however, the role of firm age is not theoretically straightforward. In fact, on the one hand, older firms are better equipped to assess the risks and benefits of introducing new technologies, while, on the other hand, younger enterprises are believed to be more flexible in dealing with the organizational changes that come with adopting ICTs. The empirical evidence is inconclusive, in general finding either a non-significant (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 we consider are exposure to international competition (exporter) and the need to be early adopters of ICT to maintain fluid communication with foreign partners (foreign direct investment, or FDI). Exporter is a dummy variable, taking the value 1 if at least 10% of the firm's sales are exported. FDI is also a dummy variable, taking the value 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 (Hollenstein 2004; Lucchetti and Sterlacchini 2004; Haller and Siedschlag 2011), and that those foreign-owned tend to be early adopters, contributing to technology diffusion in the country where they operate (Keller 2004; Narula and Zanfei 2005).

Capital city, a dummy variable that takes the value 1 if the firm is located in a capital or in a city with more than one million inhabitants, 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 et al. 2001; Karlsson 1995).

The epidemic variable calculates 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 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.

To estimate equation 4.1 for the two indicators (broadband and website), 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, we complement the probit analysis with a bivariate probit (biprobit) model (Greene 2003).

We show the marginal effects resulting from our estimations with probit in Table 4.2. Columns 1 and 2 present results for broadband connection, 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.

**Table 4.2** Determinants of broadband connection and using firm website: probit estimations

| *Variables* | *Broadband connection* | | *Website* | |
|---|---|---|---|---|
| | *Basic* | *Inclusive* | *Basic* | *Inclusive* |
| | *(1)* | *(2)* | *(3)* | *(4)* |
| Micro firm | −0.2718*** | −0.2666*** | −0.4782*** | −0.4697*** |
| | (0.0182) | (0.0182) | (0.0198) | (0.0198) |
| Small firm | −0.1433*** | −0.1403*** | −0.3084*** | −0.3040*** |
| | (0.0181) | (0.0180) | (0.0195) | (0.0194) |
| Medium firm | −0.0609*** | −0.0588*** | −0.1172*** | −0.1155*** |
| | (0.0188) | (0.0186) | (0.0203) | (0.0203) |
| Skilled human capital | 0.0022*** | 0.0022*** | 0.0023*** | 0.0023*** |
| | (0.0002) | (0.0002) | (0.0002) | (0.0002) |
| Age of firm | 0.0007*** | 0.0007*** | 0.0014*** | 0.0014*** |
| | (0.0002) | (0.0002) | (0.0002) | (0.0002) |
| FDI | 0.0138 | 0.0126 | 0.0612*** | 0.0594*** |
| | (0.0122) | (0.0122) | (0.0155) | (0.0155) |
| Exporter | 0.0868*** | 0.0876*** | 0.1115*** | 0.1120*** |
| | (0.0146) | (0.0145) | (0.0148) | (0.0148) |
| Capital city | n.a. | 0.0233*** | n.a. | 0.0458*** |
| | | (0.0070) | | (0.0094) |
| Epidemic (broadband) | n.a. | 0.1193*** | n.a. | n.a. |
| | | (0.0326) | | |
| 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 | −3010 | −2999 | −4880 | −4859 |
| Pseudo R-squared | 0.278 | 0.281 | 0.232 | 0.236 |
| Observations | 9583 | 9583 | 9583 | 9583 |

*Source*: Authors' elaboration based on WBES data

*Notes*: "Inclusive" includes the capital city and epidemic variables. 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.