The effect of broadband on economic growth in Latin America: an approach based on a simultaneous equations model

María Verónica Alderete

Abstract

This work analyses the effects of broadband on economic growth in Latin America, distinguishing between mobile and fixed broadband. Although there are studies on the countries of the Organisation for Economic Co-operation and Development (OECD), in the Latin American region such research is scarce. This work uses data from 20 countries for the period 2010–2018 and estimates a simultaneous equations model based on Koutroumpis (2009) and Katz and Callorda (2013). The results show that mobile and fixed broadband make a significant positive contribution to the region's economic growth. A 1% increase in mobile broadband penetration generates a 0.23% increase in GDP, while a 1% increase in fixed broadband increases GDP by 0.31%. This effect is greater than that found in other analyses which do not examine the complementarity between the two types of broadband.

JEL classification

O3, O4, C3, L9

Keywords

Internet, broadband, information technology, communication technology, mobile telecommunication services, economic growth, gross domestic product, mathematical models, Latin America

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I. Introduction

Broadband infrastructure is widely recognized as being a fundamental for economic growth in various countries around the world (OECD, 2009; Reynolds, 2009). The International Telecommunication Union (ITU) defines broadband as a network that offers a combined speed of at least 256 kilobytes per second (kb/s) in one or both directions (ITU, 2005 and 2006). Broadband deployment has been one of the main policy and strategic objectives of recent years, with the aim of boosting economic productivity and fostering job creation.

The most widely used research framework in this area concerning information technology and productivity is neoclassical economic growth accounting. Numerous studies have established a positive correlation between broadband penetration in a country or region and economic growth (Crandall, Lehr and Litan, 2007; Katz, 2009 and 2011; Koutroumpis, 2009; Pérez Martínez, 2012; Alderete, 2017). However, few studies examine the relationship between economic growth and mobile broadband (ITU, 2019). Unlike ITU (2019),[1] which measures the impact of broadband (both fixed and mobile) and digital transformation in the Americas region overall, this work considers the effect of both types of broadband together, not separately, and affords particular attention to the Latin American countries.

The evolution of the knowledge base underlying information and communications technologies (ICTs) in the form of recombined knowledge has fostered economic growth by applying a new core of highly complementary technologies (Antonelli, Krafft and Quatraro, 2010). On the one hand, there is a hypothesis of complementarity between fixed broadband and mobile broadband.[2] On the other, recent data show that wireless broadband is of particular interest in low-income and rural regions. While fixed broadband penetration continues to rise, mobile broadband is showing exponential growth rates in developing countries, as compared to developed ones (Thompson and Garbacz, 2011). Mobile broadband service has grown very rapidly in recent years and has already surpassed fixed broadband around the world (ITU, 2014).

The exponential economic growth of mobile broadband is not only a result of investments in infrastructure or the deployment of these technologies, but also of complementary improvements in terms of access to mobile telephony equipment and in its uses and applications. As Moore's Law works over time on processors, memory, sensors and many other elements of computer hardware (a notable exception is batteries, which have not improved their performance at an exponential rate because they are essentially chemical devices, not digital ones), it does more than just make computing devices faster, cheaper, smaller and lighter. It also allows them to do things that previously seemed out of reach (Brynjolfsson and McAfee, 2014, p. 27).

Mobile broadband services offer further reach and lower costs, unlike fixed broadband services, which are characterized by limited reach and high capital costs. In addition, they provide extraordinary access to highly personalized experiences on the Internet. In fact, mobile telecommunications profoundly affect the way users interact and produce significant externalities for the economic activities in which they are used (Gruber and Koutroumpis, 2011). Likewise, mobile Internet use requires fewer digital skills and incurs lower financial costs than using desktop or laptop computers (Stork, Calandro and Gillwald, 2013).

In several developing countries, farmers use mobile phones to find the best prices for their products (Kotelnikov, 2007). In Kerala (India), fisherfolk use mobile phone services to boost their profits by finding out when average fish prices stabilize and fall. Fisherfolk can avoid product (fish) wastage and high transaction costs by collecting market information via mobile phones. Both buyers and sellers thus achieve a higher level of well-being.

[1] At the time of submitting this article, the research had not yet been published.

[2] Broadband refers to high-speed Internet access. In the case of fixed broadband, the Internet is accessed via a cable modem, fibre optics or other similar means. Conversely, mobile broadband affords access to all Internet functionalities without a direct connection to a land line.

The percentage of e-commerce transactions carried out over mobile devices and applications is still low in Latin America. However, e-commerce is growing rapidly in the region, which is now the second fastest growing market in the world after China. According to Mercado Libre, the e-commerce platform for business-to-consumer (B2C) and consumer-to-consumer (C2C) transactions, e-commerce will represent 50% of all commerce in 2019 (GSM Association, 2014).

Mobile broadband is more widespread in Latin America than fixed broadband, because of the diversity and affordability of cellular equipment, and the greater deployment of mobile telephone networks. In 2013, the average penetration of mobile broadband in the region was 30%, while the penetration of fixed broadband was 9%. These percentages are lower than those in OECD countries, which have values of 79% and 29% for mobile and fixed broadband, respectively. Of 18 Latin American countries, mobile broadband showed greater penetration than fixed broadband in 16 (ECLAC, 2016a). Between 2006 and 2013, the growth rate for fixed broadband was 5%, compared to 22% for mobile broadband.

Costa Rica has a high rate of mobile broadband penetration, similar to the average for OECD countries and higher than for the rest of the Latin American region. Brazil has the region's second highest rate of mobile broadband penetration and Uruguay the third. Fixed broadband shows lower penetration than mobile broadband in these countries.

Between 2010 and 2014 fixed broadband become considerably more affordable. One way to measure this is by using the average price of 1 Mbps as a percentage of monthly per capita GDP. Meanwhile, the affordability of mobile broadband may be determined using the average price of a postpaid plan as a percentage of per capita GDP (ECLAC, 2016a). In 2010, 17.8% of (average) income was needed to access the fixed broadband service, compared to just 3.8% in 2014 (ECLAC, 2016a). In the most developed countries, such as France, Japan or the United Kingdom, less than 0.1% of monthly income was required to access fixed broadband. Meanwhile, for mobile broadband (postpaid plan) this proportion is approximately 0.6%.

In Latin America, the countries where mobile broadband is most affordable are Argentina, Chile, Costa Rica and Uruguay, with percentages of monthly per capita GDP below 2% (ECLAC, 2016a). The affordability gap between the most developed countries and the Latin American region is smaller for mobile broadband than for fixed broadband.

Lastly, in this region mobile broadband serves as a collaboration tool for fostering social inclusion (Barrantes Cáceres and Vargas, 2016). A good example is the use of mobile broadband to administer schemes to combat poverty, which enables better recipient selection and facilitates monitoring and evaluation of outcomes. Such is the case of the Opportunities programme in Mexico and *Bolsa Família* in Brazil.

This analysis seeks to examine the penetration of both fixed and mobile broadband in Latin America and its effect on economic growth. Its main contribution is the analysis of whether the two types of broadband are complementary or substitute each other. This is its main difference in relation to the study by ITU (2019), which treats each type of broadband separately. It is also an extension of the analysis by Alderete (2017), which was limited to the impact of fixed broadband on economic growth in the Latin American region. To this end, the present study uses data from countries in the Latin American region for the period 2010–2018.

The work is structured as follows: first, it describes the most recent findings on the contribution of fixed and mobile broadband to economic growth, with special emphasis on the Latin American region. Next, it develops a theoretical framework on the importance of ICT for economic growth and analyses the literature regarding the relationship between economic growth and fixed and mobile broadband. Third, it describes the methodology based on a simultaneous equations model, as well as the data sources used. Lastly, it presents and explains the results obtained and sets forth the conclusions.

II. The most recent findings

By the end of the 2000s, the limitations of high-speed networks and lack of competition in networks outside urban areas had produced negative repercussions in terms of the coverage, quality and prices of broadband services (Galperin, Mariscal and Viecens, 2012).

At the same time, there were few instruments to promote the deployment of broadband and mitigate regional disparities or meet the new connectivity requirements of households, businesses and public institutions. In this context, public measures are essential to ensure the deployment of core networks in areas where returns on private investment are limited.

Over the last few years, the Latin American region has experienced a shift towards greater public involvement in the sector. National broadband plans make up a set of initiatives by national governments to accelerate the deployment and adoption of broadband services. Latin American countries have been proactive in designing and implementing such plans, which have also been followed by increasing efforts to coordinate regional plans.

Broadband plans in Latin American countries show both common patterns and differences (Galperin, Mariscal and Viecens, 2012). In terms of policy instruments, the region's telecommunications sectors have made use mostly of public financing and investment in networks and equipment, State shares in the operation of the networks, and active industrial policy. The proliferation of national broadband plans testifies to the use of such policies to promote telecommunications.

In Latin America, 17 countries adopted broadband plans between 2010 and 2013. The main sources of financing for these were the universal service fund, government subsidies and other direct financing mechanisms, and public-private partnerships (ECLAC, 2016a). According to Iglesias, Cano and García Zaballos (2015) of the Inter-American Development Bank (IDB), among the Southern Cone countries, Chile has achieved the best value outcomes in terms of the status of its broadband plan.

Other factors that explain the need for telecommunications-oriented policies are regional disparities in infrastructure and access to telecommunications services, especially broadband. In recent decades, private investments in the sector have been concentrated in urban areas with higher per capita income. However, the real problem has been the failure to take measures to mitigate regional differences, such as the obligation to extend networks to private operators and the universal service fund.

After several years of year-on-year growth at rates of around 50%, the fixed broadband market in Latin America began to show signs of slowing. This was the result of reaching saturation point in higher-income urban areas and of the low uptake rate in low- and middle-income households (Galperin, Mariscal and Viecens, 2012).

At the same time, although growth in mobile phone subscriptions has slowed as the market reached saturation, mobile broadband has become the fastest growing market segment. The average annual growth rate of mobile broadband subscriptions was 55.3%, while that of fixed broadband was 11% (ECLAC, 2016b). Although mobile broadband only emerged recently (in 2007), it has already surpassed fixed broadband. Mobile broadband is now the main means of Internet access for 32% of the population, compared to only 10% for fixed broadband (ECLAC, 2016a).

In the developing world, mobile broadband services offer an answer to the demand for high-speed Internet access given the unaffordability of fixed broadband services. In the developed world, however, both fixed and mobile broadband consumption continue to grow steadily (ITU, 2014).

Countries differ in their mobile infrastructure. Some are upgrading their wireless communication networks to 4G, while others still have 3G networks with partial or incomplete coverage. In several developing countries, broadband access is still limited and 5G-type networks are either non-existent or have limited potential to increase online penetration (ITU, 2013).

The digitalization index measures a country's progress in terms of digital development.[3] In this regard, the Latin American region is on the borderline between emerging and transition economies (Katz, Koutroumpis and Callorda, 2013). While Chile is the best positioned country in the region, others, such as Cuba, Nicaragua and the Plurinational State of Bolivia belong to the category where the index is lowest (less than 20) (Alderete, 2017).

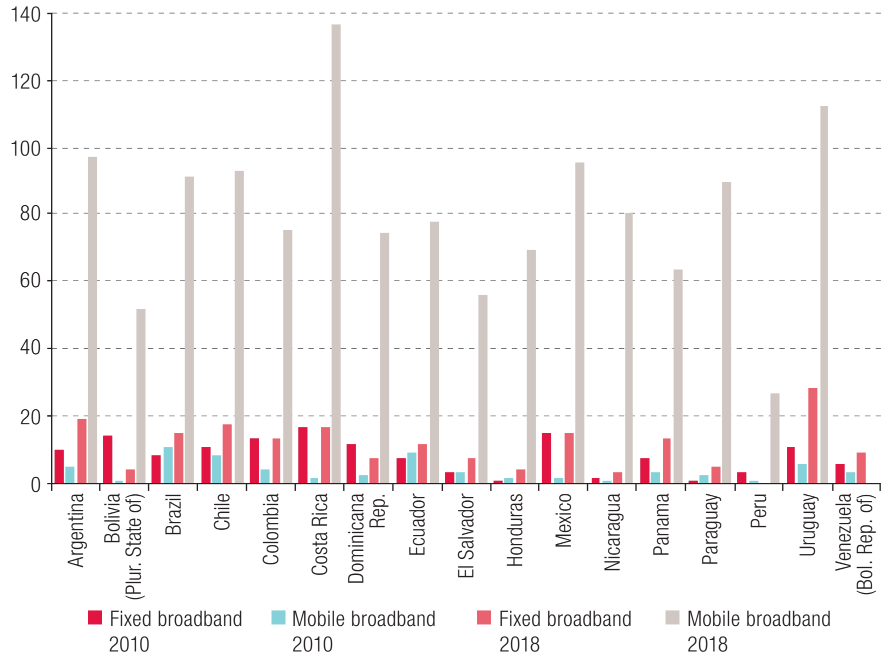
Mobile broadband is one of the most dynamic market segments, with penetration of 47% globally in 2015, 12 times the rate registered in 2007 (ITU, 2015). In Latin America, mobile broadband penetration has risen on average from 8.27% in 2011 to 44% in 2015. Conversely, fixed broadband penetration has been more stable, with rates of 5.63% in 2011 and 8.7% in 2015.

Figure 1 shows the evolution of fixed and mobile broadband penetration in 2010 and 2018 in 17 Latin American countries.

Figure 1

Latin America (17 countries): fixed and mobile broadband penetration, 2010 and 2018

(Percentages)



Source: Prepared by the author.

In 2018, the average penetration of mobile broadband in the region was 77%, while the average for fixed broadband was 12%. Uruguay is the country with the highest levels of fixed and mobile broadband, while Nicaragua and Peru have the lowest rates.

III. Theoretical framework

There is no consensus in the literature on the impact of ICTs on economic growth; however, the empirical evidence generally establishes a significant and positive effect of these new technologies on growth (Madden and Savage, 2000; Jorgenson and Vu, 2007).

[3] The digitalization index consists of six components or dimensions that capture coverage, level of access, reliability, speed, usage and capabilities. In turn, it has 24 subindicators measuring digitalization.

As with the evaluation of the economic impact of investments in ICT, determining the economic impact of broadband is no easy proposition. The relationship between ICTs and economic growth suffers from endogeneity and several authors doubt the direction of causality between the two. Countries with strong per capita GDP growth are likely to invest more in ICTs and, at the same time, countries that invest more heavily in ICTs are likely to achieve better growth outcomes. Either way, telecoms penetration rates (relative to service usage) often precede economic growth by more than telecom investments do (Jorgenson and Vu, 2007).

Roller and Waverman (2001) attempted to endogenize investments in telecommunication infrastructure in a group of OECD countries by specifying a micromodel of supply and demand for fixed telephony jointly estimated with a macroeconomic production function, by means of a simultaneous equations model. The model was later used as a reference for the case of fixed broadband in OECD countries (Koutroumpis, 2009), mobile telecommunications (cellular telephony) in 191 countries around the world (Gruber and Koutroumpis, 2011) and fixed broadband in Latin America (Alderete, 2017). More recently, ITU (2019) analysed the effect of fixed and mobile broadband separately on economic growth worldwide, and in the Americas region in particular. According to Koutroumpis (2009), a 1% increase in fixed broadband penetration (in countries with a penetration level below 14%) explains GDP growth by 0.008%. Meanwhile, Alderete (2017) finds that a 1% increase in fixed broadband generates an increase in output of 0.087 percentage points in Latin America. For its part, ITU (2019) finds that a 1-percentage-point increase in fixed broadband in the Latin American region generates a 0.15% increase in growth. The increase was larger in the case of mobile broadband, at 0.17%. Nevertheless, the effect is stronger at the regional than the global level for both types of broadband.

Other studies have also considered the issue of endogeneity and, to that end, have adopted alternative methodologies in the case of the United States (Crandall, Lehr and Litan, 2007; Greenstein and McDevitt, 2009). Greenstein and McDevitt (2009) found a small positive effect of fixed broadband on the United States economy. In the case of OECD countries, Czernich and others (2011) estimate that a 10-percentage-point gain in broadband penetration boosts annual per capita growth by between 0.9 and 1.5 percentage points.

In general, the impact of fixed broadband on economic growth is seen to be relatively low on average. However, there is consensus that the impact of ICTs on economic activity is underestimated, owing to the difficulty in measuring the value of intangible goods and services and the spread of ICTs based on their uses and applications (ECLAC, 2016a). Differences in the impact of ICTs have to do with the degree of maturity of the digital ecosystem, which includes factors such as an adequate broadband infrastructure, the diffusion of ICTs and the intensity of their use by individuals and companies, as well as their incorporation into productive and organizational processes.

By contrast, Waverman, Meschi and Fuss (2005) find a relationship between access to mobile telephony and economic growth, with a more significant impact in developing countries than in developed countries.

Only a few studies have analysed the relationship between fixed and mobile broadband technologies. Some authors find a complementary relationship between the two (Galperin and Callorda, 2014; Lee, Marcu and Lee, 2011; Cardona and others, 2009). However, others have found that fixed and mobile broadband substitute each other (Srinuan, Srinuan and Bohlin, 2012). Lee, Marcu and Lee (2011) examine the factors underlying the diffusion of fixed and mobile broadband and suggest that in several OECD countries mobile broadband broadly complements fixed broadband when first deployed. This work also assumes a substitution effect between the two technologies.

Thompson and Garbacz (2011) developed a model to determine the direct impact of fixed and mobile broadband use on GDP per household, based on panel data from 43 countries for the period 2005–2009. The authors estimate separate equations for fixed and mobile broadband to control for endogeneity between GDP and broadband. On the one hand, they find that mobile broadband has a direct positive effect on a country's GDP per household, with a higher impact in low-income economies than in high-income ones. They find no economic impact, however, for fixed broadband.

The fact that GDP does not capture the full benefits of ICT investments could be explained by the lag in the impact of ICT investments on a country's economy. This delay is a result of the complementary assets needed to properly exploit digital opportunities. Complementary innovations need to be in place so that general purpose technologies, such as information technologies, can produce a real impact (Brynjolfsson, 1993). In this respect, Brynjolfsson and Hitt (2003) argue that it takes an average of five to seven years for investments in computers to be reflected in businesses' total factor productivity. Complementary efforts and investments made during this time lapse contribute to that outcome.

An alternative explanation is that the impact on economic growth comes from two sources: (i) from "white-box" components such as the level of capital, investments in ICT and labour; and (ii) from a "black-box" component of total factor productivity whose origin and composition is still under discussion (Samoilenko and Osei-Bryson, 2011). In this sense, Brynjolfsson and McAfee (2014) argue that economic growth is not ended but has been held back by people's inability to process all new ideas fast enough.

In turn, Holt and Jamison (2009), obtain a positive but unspecified economic effect of broadband in the case of the United States. One of the difficulties encountered in studies of ICT impact is that its impact evolves, perhaps negatively during certain periods, as businesses experiment with new applications and reorganize their operations.

Other authors, such as Van Ark and Inklaar (2005), suggest that the impact of ICT investments on the economy may follow a U-shaped pattern. Initially, technology spreads across the country, leading to increased productivity, followed by a period of decreasing impact, as businesses experiment with the technology and learn how to make the best use of it. This learning period involves investments in complementary assets, such as human capital, and organizational changes that do not immediately translate into higher productivity.

According to the resource- and capability-based theories, the combination of complementary skills and assets produces synergistic effects on firms' performance (Taher, 2012; Rivard, Raymond and Verreault, 2006). The hypothesis in this regard would be that fixed and mobile broadband, used in combination, generate synergies in addition to their separate effects.

1. Determinants of demand for broadband

Like any other market, the broadband market is the result of dynamics between the forces of supply and demand. Some authors find that broadband adoption is restricted more by demand than by supply (Oh, Ahn and Kim, 2003; Stanton, 2004; Irani, Dwivedi and Williams, 2009). This is not surprising, given the emphasis of previous research on the uptake of technologies by households. Meanwhile, supply-side factors are not considered a problem in several countries (Irani, Dwivedi and Williams, 2009).

Lowering prices is a successful strategy to attract customers in the early stages. However, once saturation level is reached, other factors must be considered, such as perceived usefulness and social influence. These are examined by the technology acceptance model, but that analysis is beyond the scope of the present work.

Previous studies on the spread of broadband worldwide have found lower service cost to be one of the main determinants (Gruber, 2001; Gruber and Verboven, 2001; Liikanen, Stoneman and Toivanen, 2004; Koski and Kretschmer, 2005; Rouvinen, 2006). The lower the price of the broadband service, the more it is expected to spread. For the Latin American region, Alderete (2017) and ITU (2019) project that a 1% increase in the price of fixed broadband reduces subscription numbers by 0.29% and 0.15%, respectively.

At the same time, competition between platforms (based on the facilities offered by different platforms) has become a fundamental tool to reduce prices, increase user numbers, improve service quality and promote investment and innovation (ITU, 2003; Lee, Marcu and Lee, 2011). The complementarity between fixed and mobile modalities thus influences the uptake of broadband. Distaso, Lupi and Maneti (2006) establish that competition between platforms, for example between fixed and mobile broadband, can determine the spread of broadband. However, there is no consensus as to whether single or multiple standards foster the spread of mobile communications.

Lee, Marcu and Lee (2011) introduce complementarity between the two types of broadband by including the price of fixed broadband in their model as an explanatory variable for mobile demand. If mobile demand acted as a complement to fixed broadband, it should increase broadband penetration. Conversely, if mobile broadband acted as a substitute, the aggregate effect on broadband would be ambiguous. On the one hand, broadband penetration could be accelerated by competition between platforms, but at the same time it could be offset by sunk investments in fixed broadband.

According to studies from the mid-2000s, in the relatively early stages of the deployment of broadband as a service, socioeconomic factors (particularly income) explain broadband adoption more than sensitivity to price changes, even controlling for service availability (Horrigan, 2015). The adoption of ICTs, as well as the penetration of broadband, are directly related to economic development (Horrigan, 2015; Kyriakidou, Michalakelis and Sphicopoulos, 2011; Holt and Jamison, 2009; Samoilenko and Osei-Bryson, 2011). The findings with respect to the effects of income, broadband price and competition in its diffusion were mixed (OECD, 2007).

Thompson and Garbacz (2011) introduce cellular telephone subscriptions per 100 inhabitants as control variables in the demand functions as a proxy for investments in telecommunications infrastructure. Lastly, the Internet and telephony competition index is introduced both in the demand and supply functions to control for the level of concentration and regulation of the sector, similarly to the methodology used in ITU (2019).

IV. Methodology and data

A simultaneous equations model is estimated to control for endogeneity between broadband penetration and economic growth. The model is composed of two or more equations whose number is equal to the number of endogenous variables.

These models are useful when there is interdependence between two or more variables (bidirectional relationship) and simultaneous influence between the variables and the equations. The parameters are estimated based on the information provided by the system of equations.

The model to be estimated comprises a set of four equations: (i) a production function; (ii) a demand function; (iii) a supply function; and (iv) an output function. These last three functions serve to model broadband market, controlling for reverse causality.

Production is represented by a Cobb Douglas type function. In this function, expressed in logarithmic terms, GDP growth depends on variations or changes in non-ICT physical capital, skilled labour, and fixed and mobile broadband infrastructure.

According to Katz and Callorda (2013), the aggregate production function links GDP to gross fixed capital formation or investment, excluding investments in telecommunications by the private sector,[4] skilled labour (measured as the percentage of the workforce with an intermediate level of education) and fixed

[4] To distinguish between physical capital and ICT capital, the authors derive private sector telecommunications investments from gross capital formation, using data from the World Bank.

and mobile broadband infrastructures measured by their penetration rates (number of fixed and mobile broadband subscriptions). According to Madden and Savage (2000), the use of telecommunications penetration rates as independent variables in production studies may be less problematic than investment measures. This is the rationale for using broadband penetration rates instead of investment indicators. However, there are no international statistics on the tenor of investments in broadband. In this regard, the indicator of investments in telecommunications by the private sector published by the World Bank would be unsuitable, since telecommunications include other technologies, such as radio and television, apart from broadband.

The demand function relates the broadband penetration rate to the price of the basic broadband service (the cheapest 1 GB postpaid mobile broadband plan), the price of fixed broadband (the cheapest rate) and the per capita consumption of households. As in Katz and Callorda (2013), per capita consumption is used instead of per capita GDP, which is not considered a good indicator of income, especially in Latin American countries where there are issues regarding official statistics and labour informality. The price of fixed broadband is included to estimate the degree of complementarity between fixed and mobile broadband. The number of subscriptions to cellular telephony services is also included as a variable, in order to control for the effect of investments in broadband infrastructure, in addition to the Internet and telephony competition index to proxy the effect of concentration and regulation of the sector.

In turn, the supply function expresses the relationship between aggregate revenue from broadband sales, the level of household consumption, and urbanization rates in a given country.[5] Given that the deployment of mobile broadband is correlated with urban concentration, the broadband supply should show this structural trend (Katz and Callorda, 2013). Likewise, the equation includes the control variable of the Internet and telephony competition index as a proxy for the effect of concentration and regulation of the sector.

The output function relates the annual change in mobile broadband penetration to revenue from broadband sales. This change is used as an indicator of annual investment in broadband capital. This function assumes a stable and constant relationship between sales and investment, which is not always the case (Roller and Waverman, 2001; Koutroumpis, 2009). A system of equations is thus constructed, with the following functions:

ln GDP = $\alpha 1$ ln non-TIC capital pc + $\alpha 2$ ln skilled labour + $\alpha 3$ fixed broadband + $\alpha 4$ mobile broadband + $\varepsilon 1$

ln broadband = $\beta 1$ ln consumption pc + $\beta 2$ ln mobile broadband price + $\beta 3$ fixed broadband price + $\beta 4$ ln mobiles + $\beta 5$ ln competition index + $\varepsilon 2$

ln broadband revenues = $\beta 1$ ln consumption pc + $\beta 2$ ln urbanization + $\beta 3$ ln competition index + $\varepsilon 3$

ln broadband penetration = $\beta 1$ ln broadband revenues + $\varepsilon 4$

The STATA 14 software is used to estimate the model. Table 1 summarizes the information on the variables included in the model, with their nomenclature and the sources of the data.

The model is estimated for 20 Latin American countries: Argentina, Bolivarian Republic of Venezuela, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Plurinational State of Bolivia, Trinidad and Tobago, and Uruguay.

The data correspond to the period 2010–2018, since data on broadband prices are available from 2010 on. Table 2 shows the values of the descriptive statistics of each of the model variables in logarithmic values.

[5] The dependent variable is the income from broadband sales, be it fixed or mobile (broadband subscriptions or penetration rate). Unfortunately, there is no information available for all the years in the region on investments in mobile and fixed broadband infrastructure. Therefore, the revenue is calculated as the product between the price and the number of subscriptions.

Table 1
Description of the variables

Variables	Abbreviation (in ln)	Description	Source
GDP	lgdp	GDP at constant 2010 prices	World Bank
Non-ICT capital	lnonICTcapital	Gross fixed capital formation, excluding investments in telecommunications by the private sector	World Bank
Skilled labour	llabour	Workers with an intermediate level of education	World Bank
Mobile broadband	lmb	Active subscriptions to mobile broadband per 100 inhabitants	International Telecommunication Union; Latin American Telecommunications Research Centre (cet.la)
Fixed broadband	lfb	Percentage of subscriptions to fixed broadband	World Bank
Consumption	lconsumption	Household final consumption expenditure per capita at constant 2010 prices	World Bank
Price of mobile broadband	lpricemb	Cheapest postpaid mobile broadband plan, in dollars	Regional Dialogue on the Information Society (DIRSI)
Price of fixed broadband	lpricefb	Cheapest fixed mobile broadband plan, in dollars	DIRSI
Urbanization	lurban	Urban population	World Bank
Mobile phones	lmobiles	Number of mobile phone subscribers	World Bank
Competition index	lcompetitionindex	Internet and telephony competition index	United Nations Conference on Trade and Development (UNCTAD)

Source: Prepared by the author.
Note: Prices for 2017–2018 are not published, but were estimated based on changes in industry revenue and changes in the number of broadband subscriptions.

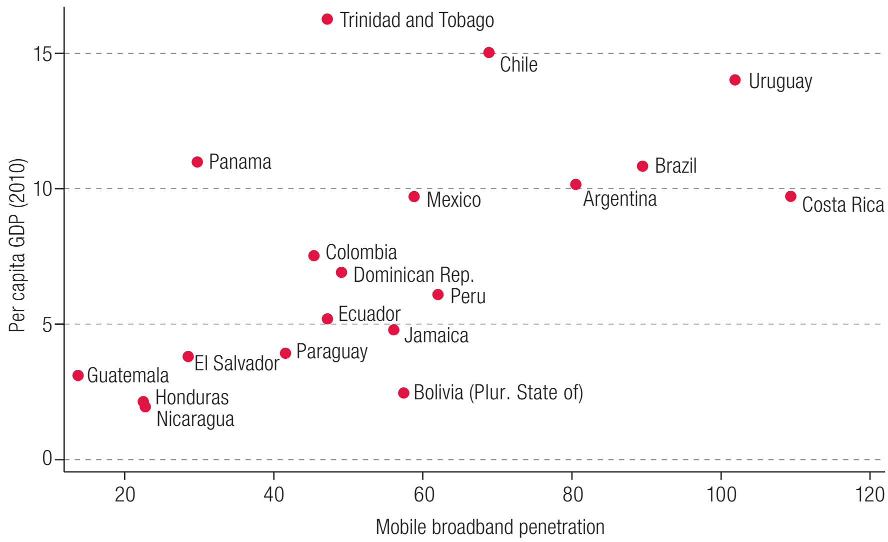
Table 2
Descriptive statistics values

Variable	Observed	Median	Standard deviation	Minimum	Maximum
lgdp	176	12.26427	6.831249	7.330733	28.47296
llabour	148	4.249583	0.0727308	4.110412	4.407629
Lnonictcapital	166	23.64896	1.509135	21.50059	27.0308
lmb	172	2.977212	1.332224	-0.6931472	4.914711
lfb	175	1.923959	0.9442899	-4.333541	3.344134
lconsumptionpc	166	8.302599	0.5934321	7.0988	9.221013
lpricemb	145	2.309964	0.8007946	-1.915537	3.952013
lpricefb	167	2.827548	0.383233	1.565946	3.855486
lincome_ba~a	138	6.001672	0.8511836	3.640769	7.502315
lurban	180	4.182219	0.4483579	2.122501	4.558707
lpenmb	139	1.777137	1.321302	-2.813324	3.935544
lpenfb	126	-0.2356156	1.111347	-3.566671	2.7888
lcompetitionindex	98	1.359708	0.7849852	-0.4004775	2.079442

Source: Prepared by the author.

An exploration of the data was carried out to analyse the relationship between the per capita GDP variable and the penetration of fixed and mobile broadband prior to the causal study between broadband penetration and economic growth. To this end, figure 2 first shows the correlation between the percentage of mobile broadband subscriptions and per capita GDP for 2016 (period with positive growth rates). A certain pattern may be observed in the region, whereby countries with low rates of mobile broadband penetration show low levels of per capita GDP.

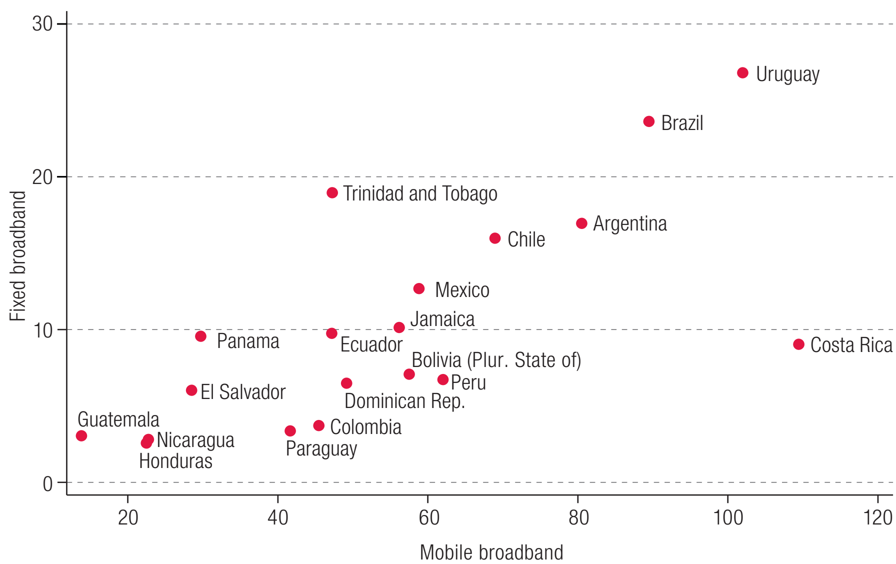
Figure 2
Latin America: per capita GDP and penetration of mobile broadband, 2016
(Thousands of dollars and percentages)



Source: Prepared by the author.

Figure 3 depicts the relationship between the two types of broadband and shows an apparently positive relationship between the two variables. On the one hand, there are countries with very low mobile broadband penetration that also have low fixed broadband penetration. On the other, there is a group of countries with a greater penetration of both mobile and fixed broadband (Argentina, Brazil, Chile and Uruguay, among others).

Figure 3
Penetration of fixed and mobile broadband, 2016
(Percentages)



Source: Prepared by the author.

V. Results and discussion

This work estimated a simultaneous equations model based on Koutroumpis (2009) and composed of four functions: the production function, the mobile broadband demand and supply functions, and the output function. First, the production or GDP growth function is estimated (see table 3); this achieves adequate goodness of fit (R2 = 0.99). Two different models are proposed, one that includes the Internet and telephony competition index (model 1) and model 2, which does not. Since no data were found for this index for the years 2010 and 2011, many observations are missing in model 2. However, both models are estimated to show that the effects of broadband are quite robust even in the absence of this variable.

Table 3
Results of the models estimated
(Coefficients)

Function	Variables	Model 1		Model 2	
		Coefficients		Coefficients	
GDP growth	Labour (llabour)	1.234821		0.3716344	
	Non-ICT capital (lcapital)	0.329578***		0.3417165***	
	Penetration of mobile broadband (lmb)	0.2056119**		0.2639624***	
	Penetration of fixed broadband (lfb)	0.345902***		0.2937888***	
		Mobile broadband	Fixed broadband	Mobile broadband	Fixed broadband
Demand	Price of mobile broadband (lpricemb)	-0.3586388***	-0.2570329**	-0.2056073***	-0.1863914**
	Price of fixed broadband (lpricefb)	-0.0699065	0.1701258	-0.21379*	0.1406662
	Household consumption (lconsumption)	0.7807555***	1.119162***	0.7395554***	1.052132***
	Competition index (lindex)	0.0412268	-0.4825844***		
	Mobile phones (lcelulares)	0.1815498	0.1364271	0.2848965	0.2609025
Supply (lingresob)	Household consumption (lconsumption)	0.5019935**		0.4616062***	
	Urbanization (lurban)	1.420929**		1.563048***	
	Competition index (lindex)	0.1987062**			
		Mobile broadband	Fixed broadband	Mobile broadband	Fixed broadband
Output (lvarb)	Income from broadband (lincomeb)	0.6824236***	0.552166***	0.4504333***	0.5755936***
Effects in years		Yes	Yes	Yes	Yes
Observations per function		53	53	83	83
R2	GDP growth	0.9940		0.9946	
	Demand	0.7741	0.6370	0.7365	0.5990
	Supply	0.5066		0.4843	
	Output	0.3039	0.3128	0.2294	0.2402

Source: Prepared by the author.
Note: *, ** and *** represent variables significant at 10%, 5% and 1%, respectively. The years 2016 and 2018 were significant, with a growth rate that was negative in 2016 and positive in 2018. Meanwhile, lvarb is the variation in broadband penetration in log terms (penetration t - penetration t-1).

The parameters estimated from this function show that non-ICT capital, mobile broadband and fixed broadband are significant production factors and have a positive effect on economic growth. In other words, higher levels of capital investment and penetration of both fixed and mobile broadband generate greater economic growth. According to the model estimated, a 1-percentage-point increase in mobile broadband penetration produces a gain in GDP growth of 0.20 percentage points in model 1 and 0.26 percentage points in model 2. This result is significant at the 5% and 1% level, respectively, and higher than previous studies on broadband, both in the region (Katz, 2009 and 2012; Katz and Callorda, 2013; ITU, 2019) and beyond (Czernich and others, 2011).

In turn, fixed broadband has a positive and significant effect, although larger and at a higher level of significance than mobile broadband: 1 percentage point of fixed broadband penetration produces an increase in growth of GDP of 0.34 percentage points in model 1 and 0.29 percentage points in model 2. This result contrasts with those of other authors, who found a non-significant (Holt and Jamison, 2009) or negative (Thompson and Garbacz, 2011; Van Ark and Inklaar, 2005) effect of fixed broadband using data from non-Latin American countries. In other words, contrary to the findings of the present study, these authors found that higher levels of fixed broadband penetration would lead to lower economic growth rates.

However, the results obtained in the present work confirm the recent findings of Alderete (2017) for the Latin American region. A reasonable explanation for the higher incidence of fixed broadband is that, considered in isolation (without mobile broadband), it fails to capture the full benefits of broadband overall. This result may also speak to the relevance of the "black box" of complementary assets that are a second source of productivity. Complementary assets refer to the abilities, skills and creativity to combine the new knowledge and ideas emerging in the digital world. In the case of mobile broadband, which is more widespread than fixed broadband, this "black box" is clearer or more evident. The deployment of this platform does not require such large investment in infrastructure as fixed broadband does, nor does it need a dedicated infrastructure per consumer. In fact, ubiquity is its main advantage, which explains the higher levels of mobile broadband penetration. The population with lower resources has already accessed mobile broadband services (Flores and Mariscal, 2012). However, not including both technologies in the estimation could cause their true impact to be underestimated, if a complementary relationship between the two types of broadband is found, as in this case.

At the organizational level, as businesses take up ICTs, they start to venture into more digital spaces or media, which provides evidence for the idea of complementarity in technology (Torrent-Sellens and Ficapal-Cusí, 2011; Bresnahan, Brynjolfsson, and Hitt, 2002).

Nonetheless, the non-significant finding for labour could reflect lack of data in some countries of the region on the percentage of the labour force with intermediate levels of education. In order to determine whether lack of data was the issue, an alternative model was estimated based on research and development spending instead of workers with intermediate education. In this case again, the variable was not significant in explaining economic growth.[6] This result is also consistent with some current lines of thought regarding the displacement of labour caused by new technologies (Acemoglu and Restrepo, 2017).

Regarding the demand function, as predicted by theory, an increase in per capita consumption —used as a proxy for disposable income— generates a significant effect on broadband demand. Since the variables are expressed in logarithmic terms, the coefficient for income represents the income elasticity of broadband, indicating that broadband functions as a normal good. However, mobile broadband is a necessary good, since for every percentage point increase in disposable income, the number of mobile broadband subscriptions demanded increases by 0.78%. Meanwhile, fixed broadband is a luxury good, since for each percentage point increase in disposable income, the number of mobile broadband subscriptions demanded increases by 1.1%. Analysis of the determinants of broadband price shows that demand for fixed broadband is not explained by its own price. Conversely, demand for mobile broadband is explained by its own price. Demand for fixed broadband is negatively related to the price of mobile broadband. A negative coefficient would indicate the existence of a complementary relationship between the two services (cross elasticity less than zero).

A review of the literature on the existence of complementarities in technology refers to authors such as Bae, Choi and Hahn (2014), Grzybowski and Verboven (2013), Dewan, Ganley and Kraemer (2010) and others less recent, such as Bayus (1987) and Bucklin and Sengupta (1993). Grzybowski and

6 The results obtained in this case are available from the author, for readers interested in them.

Verboven (2013) show that fixed telephony and mobile voice services are weakly complementary. Dewan, Ganley and Kraemer (2010) have examined complementarities in the diffusion of multiple products and innovations. In particular, complementarities in the spread of computers and the Internet have led to the reduction of digital divides. Bayus (1987) examines complementarities in sales of hardware and software. Bucklin and Sengupta (1993) test the complementarity effects of co-diffusion between scanners and universal product codes. Similarly, the present work analyses the complementarity between fixed and mobile broadband and its possible contribution to reducing the digital divide in favour of developing countries. The direction of complementarity found is somewhat different to the studies mentioned, however, as fixed broadband appears to complement mobile broadband and not the other way around. This is a reflection of the greater penetration of mobile broadband in this region.

The competition index, meanwhile, was only significant in relation to demand for fixed broadband. Since full liberalization in telephony services implies a score of 2, the higher the level of competition in the fixed broadband sector, the higher the demand for fixed broadband. This index was not significant in the demand for mobile broadband. Lastly, the cellular phone control variable was not significant.

According to the supply function, the urbanization rate has a significant effect. In other words, increases in the supply of broadband services are explained by urbanization growth. For every percentage point increase in the urbanization rate, the supply of broadband increases by 1.42 percentage points. Supply is also explained by the level of per capita consumption and the competition index. In the latter case, the sign is opposite to that obtained in the demand function.

Lastly, revenues or profit from the sales of both mobile and fixed subscriptions have a significant effect on the broadband penetration equation. Bearing in mind the lag in ICT investments —since it takes time for these to generate an impact on a country's economy— the significance of the output function or broadband penetration function is to be expected.

VI. Conclusions

This work offers a contribution to the empirical literature on the impact of new ICTs, particularly broadband, on economic growth. Numerous studies have been published on the subject recently for OECD countries, or for all countries generally. However, few studies focus on the Latin American region.

The present work's main contribution is to extend the analysis of the impact of broadband on economic growth to include the penetration of mobile and fixed broadband jointly. In this sense, the impact of broadband in the region is unlikely to be the same as in other world regions, given the broader context in which ICTs are deployed and the conditions under which they have contributed most effectively to growth.

According to the review of the international literature, the effect of fixed broadband on economic growth has been lower than expected, and sometimes even negative. As mentioned in the article, a possible explanation for this is that ICT access (in this case, fixed broadband penetration) cannot explain the total effect of these new technologies on economic growth. Another criticism advanced of such studies is that including fixed broadband in the production function, without also including mobile broadband and therefore omitting its impact, could bias the effect. This hypothesis would be robust if a complementary relationship is assumed between the two types of broadband.

The result of the simultaneous equations model used is that the penetration of mobile broadband partly corresponds to the economic growth of the countries of the Latin American region. Specifically, a 1% increase in mobile broadband penetration causes an increase in GDP of around 0.23% (average of both models). In turn, a 1% rise in fixed broadband penetration causes GDP to rise by around 0.31%

(average of both models). These effects found for broadband are greater than the effects obtained for fixed broadband in previous studies for the region (Alderete, 2017) and beyond (Koutroumpis, 2009; Czernich and others, 2011), and those obtained by ITU (2019).

The model also finds fixed broadband to have a larger positive impact on GDP growth, with the result of greater magnitude than the impact of mobile broadband, which contrasts with studies carried out on fixed broadband in developed countries. This last point may be explained by the fact that previous studies do not treat the two types of broadband together (and, therefore, do not consider complementarity between them). In the case of fixed broadband, the economic impact will likely not be immediate and will require complementary investments. For example, it is necessary to take into account how long the technology has been in use and the adaptation period, during which business may be experimenting or learning from these technologies and making the related organizational changes. In the case of mobile broadband, although complementary investments may be made, a lower level of digital skills and additional expenses are required.

In terms of theoretical implications, this work follows the line of previous studies regarding the existence of complementarities in technologies (Dewan, Ganley and Kraemer, 2010; Bayus, 1987; Bucklin and Sengupta, 1993). It also analyses the complementarity between fixed and mobile broadbands and their contribution, through the synergies generated, to boosting the effect on growth and reducing the digital divide in favour of developing countries.

In terms of practical implications, the combination of different types of technological infrastructures becomes evident in the field of e-commerce. The deployment of an e-business model combines sales platforms with different digital media, such as mobile applications and social networks. To these are added corresponding internal processes, as well as intangible factors such as relational capital, to integrate the different agents involved in the platform and the skills to manage projects.

In terms of policy implications, this work serves as a basis for promoting policies related to broadband, especially mobile broadband, given its significant impact on economic growth in the Latin American region. It also proposes the need to implement policies in a comprehensive manner to address the determinants of both demand and supply of mobile broadband connectivity. In this regard, the results explain the higher penetration rates of mobile broadband in countries with a higher level of per capita income, and the predominance of mobile broadband services in countries with a higher percentage of urban population. A more in-depth analysis of these results shows that the advantages that these new technologies offer for economic growth are not available to the most marginalized or excluded sectors of the population, such as the rural population or those with lower levels of per capita income. It is therefore necessary to distinguish between growth-oriented policies and policies with redistributive or inclusive aims.

In any case, the fact that the introduction of mobile broadband causes a more significant impact than fixed broadband on economic growth is a promising result from the point of view of social inclusion. First because mobile broadband requires less investment in infrastructure than fixed broadband and, second, because the financial costs associated with both the equipment and the cost of the service are lower in the case of mobile broadband. In addition, fewer digital skills are required to use mobile broadband than fixed.

This study focuses on the countries of the Latin American region. However, its results could be useful for understanding the relationship between broadband penetration and economic growth in other developing economies. Thus, the results obtained in developed regions could be compared with those of developing regions.

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