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Abstract

The importance of connectivity is growing across the world as the need for access to information and communication technologies is becoming more important for economic development. This paper presents the concept of the connectivity frontier as the expected achievable level of commercially sustainable connectivity for information and communication technologies for each country given the average country's structural and institutional endowments. The connectivity frontier is computed, identifying the key structural and institutional variables that affect connectivity investment in a country. The study uses the connectivity frontier as a benchmark to compare connectivity levels across countries and identify connectivity gaps, illustrating the connectivity gap analysis with an application to Latin American and Caribbean countries. Finally, the paper includes an analysis of the determinants of the connectivity gap using panel data for OECD countries, showing the importance of entry regulation and public ownership to explain the observed connectivity gap.

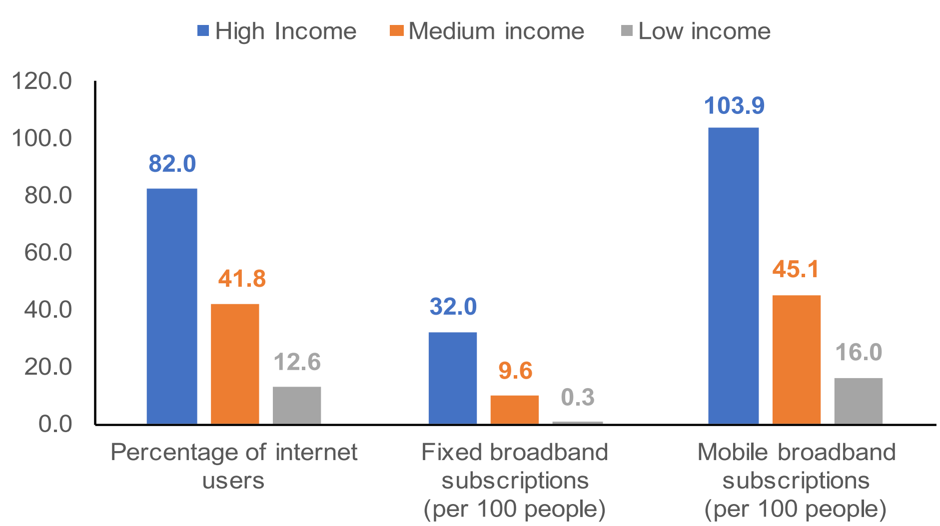
JEL Codes: L86, L96, L98
Keywords: connectivity frontier, economic structure, internet services, institutions, telecommunications

1. Introduction

Connectivity provided by information and communication technologies (ICTs) is revolutionizing the way we do things. From the transportation to the health and education sectors, myriad innovations are creating opportunities for developing new business models and improving people's capabilities. Connectivity is key for economic and social development, and access to ICTs was included in the United Nations Millennium Development Goals. Connectivity (Target 8.F), specifically high-speed internet access, provides opportunities for people, businesses, and governments to expand their capabilities through new ways to learn about and deliver services and products. At an empirical level, several studies estimate a strong relationship between ICTs and economic growth (Minges, 2015). At the same time, there is an increasing demand for connectivity, since it provides important benefits in terms of improving people's lives and business opportunities.

There is also wide heterogeneity in access to ICT services among countries in terms of depth, breadth, and quality of these services. Countries vary in the depth in which they access different services (i.e., number of internet connections), the types of services (mobile, fixed, and broadband subscription lines, among others), as well as the price and quality of these services (price per megabit, download and upload capacity measured in megabits per second, and others). These are significant differences in terms of the type of access that people, businesses, and governments have in each country and, thus, their possibilities to take advantage of ICTs to improve their welfare.

Figure 1. Access to ICTs by Level of Income (2016)



Source: Authors' elaboration based on International Telecommunication Union.

This paper studies the differences in access to ICTs services across countries through the lens provided by the concept of the connectivity frontier. Borrowing the idea from other gap analyses, such as the financial possibility frontier in Beck and Feyen (2013), we apply the frontier concept to connectivity, defined as access to internet services. The connectivity frontier is understood as the share of the population in a country that can be commercially served in a sustainable manner given its structural (i.e., economic development, population density, and orography) and institutional (i.e., regulatory capacities, ICT policies, and others) endowments. In more technical terms, the connectivity frontier is the average level of access to internet services constrained by structural and institutional conditions. The connectivity frontier is a useful tool for assessing the gap between the actual connectivity level and the expected connectivity once these constraints are factored in. This exercise provides a framework to analyze the root causes of connectivity deficits and give policy recommendations. It is related to the literature on the importance of connectivity and internet access for economic and social development (Minges 2016), the benchmarking of different technological sectors around the world as in Beck and de la Torre (2007) and Beck and Feyen (2013), and the determinants of the structure of the telecommunications market (Faulhaber and Hogendorn, 2000).

2. The Connectivity Frontier: A Conceptual Framework

Digital technologies have spread rapidly around the world, boosting growth, expanding opportunities, and improving service delivery. However, their aggregate impact has fallen short of expectations, mainly due to the digital divide created by uneven internet access across the world (World Development Report, 2016). This means that some countries are falling behind in terms of connectivity and, hence, losing out on the benefits of the so-called information society (Castells, 2000 or the fourth industrial revolution (World Economic Forum, 2016).

To understand why a country is losing ground in terms of connectivity requires an appropriate benchmark—one that considers not only the desired level of connectivity, but also the expected level of connectivity considering the constraints imposed by the inner characteristics of the telecommunication infrastructure and the country's structural and institutional endowments. This is precisely what the concept of the connectivity frontier tries to achieve: to provide a benchmark to assess realistically a country's level of connectivity. With such a benchmark, it will be possible to compare connectivity levels across countries, understand the causes of connectivity deficits and surpluses in a country, and provide policy recommendations accordingly.

Connectivity is provided through telecommunications and digital infrastructure. The transmission of a large amount of data between remote hosts and end users at high speeds requires shared facilities capable of transferring data at rates considerable greater than traditional telephone networks,[1] as well as access facilities to connect individuals to the public or shared network. Public or shared facilities are usually called core infrastructure (and backhauls), while access facilities are referred to as last-mile facilities.

Along with the disruptive change in ICTs, telecom infrastructure networks have undergone a radical transformation in the last 25 years. In this period, the digitalization of information transmission, the more efficient use of the electromagnetic spectrum, and the deployment of new broadband infrastructure have all contributed to increased connectivity in terms of quantity and quality. This process entails two major components: investment and regulation.

Investment decisions in the telecommunications sector are subject to important sunk and fixed costs that create natural monopoly characteristics in important parts of the telecommunication infrastructure network, especially in the backhaul and core components of the network. High capital costs are typical in other public utilities infrastructure systems as well, such as energy or water and sewerage, in which service availability implies important fixed costs and there are also network externalities. These externalities emerge as the value of a person to be connected to a network increases welfare for both the individual and the network. All these characteristics are affected by a country's structural endowment, such as the level of development, the density of the population, or its geographic conditions. These conditions cannot be affected in the short or medium term by economic policy decisions; rather, they correspond to the structural conditions under which the country should promote its economic development.

At the same time, due to the specifics of telecommunications markets, the institutional structure is key to control monopoly power, regulate competition, and achieve universal service, in which almost all the population has access to broadband services. These tasks make the role of the regulator highly complex, since it needs to regulate complex issues such as access and interconnection prices, investment requirements for new entrants, and anti-competitive practices. To perform these tasks, a country needs an

[1] Data transfer rate are traditionally expressed in bits per second, with voice telephone services using approximately 10 Kbps (narrowband facility) and cable television 10 Mbps (broadband facility).

institutional environment capable of adhering to a stable set of rules and responding flexibly to changing circumstances (Levy and Spiller, 1994). Building the institutional environment required to support good telecommunication regulation or a connectivity strategy is a long-term policy process. The rules and organizations required to delegate authority to highly professionalized and independent administrative bodies, enforce policy decisions, and provide a credible policy framework are built through historical processes and cannot be changed through short-term policy decisions.

For these reasons, when assessing a country's level of connectivity, it is important to consider the structural and institutional conditions in which connectivity takes place. This is precisely what the connectivity frontier concept does. Since structural and institutional factors can hold back the connectivity possibilities of a given country, it is key to distinguish these factors from policy restrictions that keep a country below the frontier.

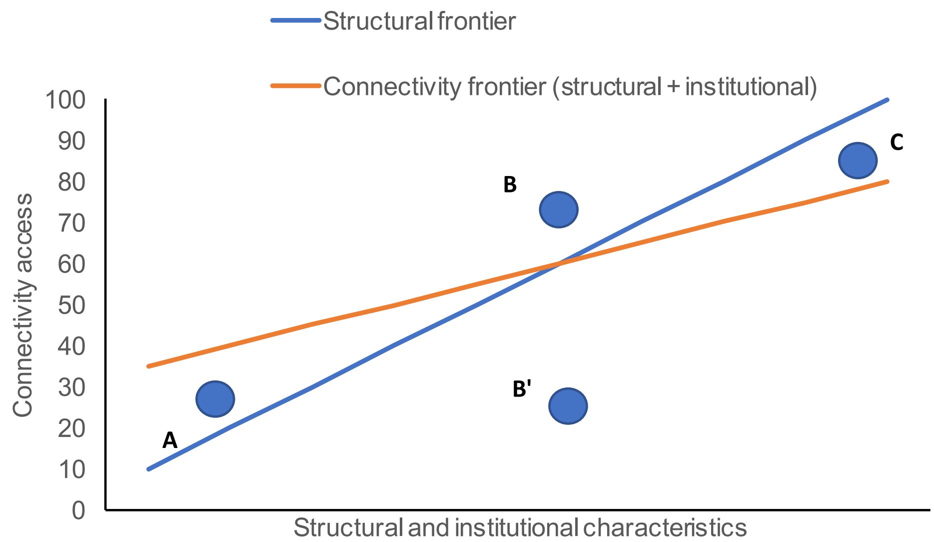
Structural conditions refer to the socioeconomic and geographical conditions in a country that affect its capacity to develop connectivity infrastructure. There are three main structural conditions. The first is the level of socioeconomic development. Even when it is well-known that connectivity causes economic growth, the level of economic development also plays a role in explaining the telecommunication infrastructure in several ways. Previous sunk investments (i.e., in fixed telephone lines) play a significant role in connectivity deployment costs, and the socioeconomic level of a country also influences a country's capacity to invest and to use the new digital infrastructure. Second, the level of population density of a country also influences internet and broadband infrastructure deployment costs. Population density increases revenues per connected user since it allows operators to acquire customers using the same core infrastructure. In countries with lower population density, in which rural areas are predominant, the costs of connectivity are higher since network effects are much lower and the fixed cost per user is higher. Finally, geographic conditions can also play a significant role in network development and internet access. In countries where a high percentage of its terrain is rugged and wild, network investment can be costly. In example, a high percentage of mountains or are big variations in relative altitudes in the country could affect network costs and infrastructure deployment strategies. Short-term policy decisions cannot affect any of these conditions; they are, to a considerable extent, exogenous to the policy realm.

Institutional conditions are the formal and informal rules and processes that structure economic and social interactions. In practical terms, they refer to the capacity of a given country to design and enforce sound regulations through democratic, accountable, and credible processes. In the case of telecommunication infrastructure, this is particularly important since a high percentage of the investment is sunk or irreversible and, hence, is subject to the so called “hold-up” problem. A credible institutional framework is key to induce long-term investment, which is required for connectivity. The capital cost, and thus the firm’s reluctance to invest, increases with political (i.e., expropriation) and contractual (i.e., tariff changes) risk. Underinvestment in connectivity may thus be the result of a weak institutional environment. The institutional environment in this case is not the telecommunications regulatory framework, but the broader political and legal context.

Analyzing the frontier allows us to distinguish between four different scenarios (Figure 2). In the first scenario (country A), the connectivity level in a country can be below the connectivity frontier (structural and institutional endowments), but above its structural frontier. This means that the country has a high level of connectivity based on its structural characteristics but that, controlling for the level of its institutions, the expected average connectivity should be greater. In this case, a market regulation problem might be the answer since the commercial conditions are present and no firm is entering the market. Market entry and competition regulations are key in this respect. The second scenario is that of a country that is above both the structural and the connectivity frontiers (country B). In these cases, the country is above the expected average, because of a policy distortion, such as a subsidy introduced through a public firm or a public policy that sustains a connectivity level above what is commercially viable.

The third scenario is when a country is below both average frontiers (country B’), which means that the country has low structural and institutional conditions that restrict the level of connectivity it can achieve. These constraints are exogenous (such as the terrain rugosity) or cannot be affected in the short term (the level of economic development). In these cases, to overcome these barriers, long-term growth policies should be expected and put in place. Finally, the fourth scenario is when the country is below its average structural frontier, but above the expected level according to its institutional characteristics (country C).

Figure 2. Structural and Connectivity Frontier



Source: Authors' elaboration.

3. Identifying the Connectivity Frontier: A Macro Quantitative Approach

We use an econometric approach to operationalize the connectivity frontier, estimating access to the internet through its main structural and institutional determinants. We use a cross-country panel to construct an internet connectivity time-variant benchmark model by determining the predicted regression value of different connectivity indicators based on a selection of country characteristics. In this case, we do not consider the frontier as a maximum achievable level of connectivity with respect to best connectivity-performing country, but as an average benchmark based on our countries' structural and institutional endowments. We estimate the following stylized model:

$$CI_{i,t} = \beta X_{i,t} + \delta I_{i,t} + \beta_t + u_{it} \quad (1)$$

The connectivity frontier is estimated using three connectivity indicators in country i in year t. The connectivity indicators used in this paper are the percentage of individuals that have used the internet from any location in the last three months, the number of subscriptions per 100 inhabitants for fixed broadband internet, and the number of subscriptions per 100 inhabitants for mobile broadband internet. The information on all of these indicators comes from the International Telecommunications Union Database.

A set of structural country-specific variables are captured in variable $X_{i,t}$. Among these, we include those described in the previous section and that theory predicts have an influence over all connectivity. First, we measure the socioeconomic level of a country by its GDP per capita. Specifically, we use the level of GDP per capita in 1996 to avoid endogeneity bias due to the relationship between growth and internet penetration described previously (Minges, 2016). Second, we measure population density through the people per square kilometer of land area in a country. Data on both variables are taken from the World Bank's World Development Indicators. Third, as geographic variables we introduce a measure of terrain rugosity and a dummy variable for island. To measure terrain rugosity, we use the range of terrain ruggedness of country i. Shaver, Carter, and Shawa (2016) construct this variable using information from the US Geological Surveys Center for Earth Resources Observation and Science (EROS).[2] We expect all the above coefficients to be positive except the geographic ones, which we expect to negatively impact the connectivity possibility frontier.

As an institutional variable ($I_{i,t}$), we use the government's ability to enforce the law and implement public policies as proxies for its capacity to solve to the hold-up problem explained above. A lack of state capacity to implement and enforce policies and regulations in a stable and credible manner is related to regulatory and expropriation risk that firms face, especially when investing in sectors characterized by large sunk costs, substantial economies of scale, and highly politicized pricing, such as telecommunications or electricity generation. At the same time, the literature show that the risk of expropriation can generate both a complete (or partial) withdrawal of investment from the host country (Cole and English, 1991; Thomas and Worrall, 1994) and underinvestment (Raff, 1992).

In this paper, we use the variable Rule of Law from the Worldwide Governance Indicators, because it highlights the endowment of policies that insures important business environment elements such as contract enforcement and property rights, and measures the confidence that agents have in the countries' institutions. We are aware of the potential multicollinearity problem with GDP per capita. To address this problem, we use that part of the institutional variable not explained by the GDP level, making use of the residuals of their partial correlation. Descriptive statistics for our dependent and independent variables are presented on Table 1.

[2] Shaver, Carter, and Shawa (2016) divide all land areas of the world into identical 30 arc second squares—approximately one by one kilometer—and measure the absolute elevation change between each square and its eight adjoining squares. See https://www.princeton.edu/~dbcarter/David_B._Carter/Data.html

Table 1. Descriptive Statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
Percentage of internet users	3,933	24.3	27.3	0.0	98.3
Fixed internet subscriptions	2,616	8.3	11.3	0.0	61.7
Mobile internet subscriptions	1,475	29.3	34.0	0.0	254.4
GDP per capita 1996	3,933	9,865.5	14,732.7	122.9	74,790.1
Population density	3,933	255.7	1,270.1	0.1	19,249.5
Ruggedness range	3,933	1,615.8	1,165.2	0.0	6,662.3
Island dummy	3,933	0.2	0.4	0.0	1.0
Rule of law	3,363	0.0	1.0	-2.6	2.1

Source: Authors' estimation.

We also considered other methodologies that have been applied to estimate baseline frontiers, such as data envelopment analysis and stochastic frontier models, but decided to use our methodology for several reasons. On one hand, both methodologies imply that there is a production function in which by construction the output is the result of the transformation of a number of inputs. As a result, in these cases there are optimal combinations of these inputs that allow the producer (i.e., country) to achieve an efficient production level. Meanwhile, internet connectivity indicators are not strictly a function of the previously selected structural and institutional endowments. We do, however, expect these exogenous country conditions that can be considered fixed in the short term to affect their production and penetration.

On the other hand, these models have characteristics that affect the estimation and interpretation of the connectivity gaps that we later use in Section 5, where these gaps are understood as the difference between the actual connectivity level in a country and the average one predicted by our model. For instance, the panel stochastic frontier model (Greene, 2005) uses a country fixed effect that could account for policies that are fixed in our period of observation, which we are interested in identifying to explain a country's positive or negative connectivity gap.

Table 2 reports our baseline results for the estimation of equation (1). The explanatory power of our model is significantly high, ranging from an R-squared of 0.54 for mobile subscriptions to 0.72 in the case of percentage of internet esers. Regression results show that all the variables are significant and have the expected sign. Both GDP per capita and population density are significantly and positively related to all connectivity variables used in the regression models. According to our model, a US$1,000 increase in GDP per capita (1996) could increase the percentage of internet users by 1.1 percentage points. Likewise, it can increase the penetration of fixed and mobile internet by between 0.5 and 1.4

subscriptions per 100 people. We interpret these results as a confirmation of our model where we consider that purchasing power, economic development, and market beneficial characteristics such as economies of scale generated by high population density can drive up internet access in a country.

The rule of law indicator is also positively related to all our connectivity indicators, showing the relevance of proper institutions and contract enforceability for the development of internet provision industries across countries. The regression results are robust to the introduction of other institutional variables, such as regulatory quality or political stability. On the other hand, we find a negative and significant effect of the range of terrain ruggedness of a country and the level of our three connectivity indicators. This could be explained by the fact that a very mountainous terrain with a significant dispersion in its territorial ruggedness can have a negative impact on the cost of internet infrastructure provision and the cost of access for users. Finally, our Island dummy has a negative relationship to internet penetration variables only when controlling for institutional endowments. The lower level of internet access of islands compared to peninsular countries could be linked to characteristics such as their smaller available spectrum, which can limit operators' service provision.

Table 2. Connectivity Indicator Regressions

	1996–2016 Internet users	1996–2016 Internet users	2005–2016 Fixed internet	2005–2016 Fixed internet	2010–2016 Mobile internet	2010–2016 Mobile internet
GDP per capita 1996	0.00106***	0.00111***	0.000544***	0.000544***	0.00139***	0.00135***
	(0.000022)	(0.000020)	(0.000017)	(0.000016)	(0.000074)	(0.000065)
Population density	0.00262***	0.00275***	0.00178***	0.00171***	0.00289***	0.00722***
	(0.00008)	(0.00041)	(0.00071)	(0.00041)	(0.00056)	(0.00093)
Range ruggedness	-0.000771***	-0.000526**	-0.000769***	-0.000506***	0.000469	-0.016034**
	(0.0003)	(0.0003)	(0.00253)	(0.00187)	(0.0087)	(0.0071)
Island dummy	1.519***	-3.854***	0.0805	-2.558***	-2.912*	-9.413***
	(0.571)	(0.648)	(0.404)	(0.370)	(1.544)	(1.551)
Rule of law		10.11***		4.941***		11.22***
		(0.524)		(0.358)		(1.369)
Year fixed effect	X	X	X	X	X	X
Observations	3,933	3,236	2,130	2,054	1,264	1,225
R-squared	0.663	0.718	0.577	0.666	0.536	0.596

Source: Authors' estimation.
Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

4. Connectivity Gap Analysis: An Application to LAC Countries

The second exercise we perform is to use the structural and the connectivity frontiers described above to estimate the connectivity gap in a given country. Using the coefficients from equation (1), with and without institutional endowments, we calculate the structural and the connectivity gap following equation (2) as the difference between the actual connectivity level and the average predicted by the structural and institutional variables of our model for each country i in year t. Table 3 shows the expected average values of the structural and connectivity frontiers for LAC countries, with which we construct these gaps.

Table 3. Structural and Connectivity Frontiers for LAC Countries

	Percentage of internet users			Fixed internet subscriptions per 100 people			Mobile internet subscriptions per 100 people		
Country	Observed	Structural	Connectivity frontier	Observed	Structural	Connectivity frontier	Observed	Structural	Connectivity frontier
Argentina	**70.2**	46.3	45.8	**16.9**	10.3	10.3	**78.1**	52.7	52.1
Barbados	**79.5**	57.5	60.4	**30.1**	16.7	17.7	**45.3**	59.7	64.1
Belize	**44.6**	43.2	38.9	**6.2**	9.6	7.5	**13.4**	46.7	42.1
Bolivia	**39.7**	40.2	33.4	**2.6**	7.5	4.4	**56.6**	43.9	36.8
Brazil	**59.7**	47.8	49.6	**13.0**	11.5	12.4	**88.5**	53.8	55.5
Chile	**66.0**	46.3	59.1	**16.0**	10.0	16.6	**72.1**	53.3	67.5
Colombia	**58.1**	40.9	42.2	**11.8**	6.4	7.8	**46.9**	48.0	50.3
Costa Rica	**66.0**	45.2	52.6	**11.6**	10.3	14.0	**108.0**	49.9	58.4
Dominican Republic	**61.3**	44.8	40.1	**6.5**	9.6	7.3	**49.8**	44.1	39.3
Ecuador	**54.1**	42.7	40.2	**9.7**	8.7	7.7	**46.9**	47.2	44.9
El Salvador	**29.0**	43.1	40.6	**6.0**	9.5	8.3	**29.1**	46.6	45.3
Guatemala	**34.5**	39.9	35.1	**3.0**	6.6	4.8	**13.9**	45.1	41.1
Guyana	**35.7**	41.7	43.2	**7.6**	8.7	9.5	**0.2**	45.0	46.9
Haiti	**12.2**	42.6	33.0	**0.0**	8.5	3.9	**10.2**	41.2	32.0
Honduras	**30.0**	40.9	35.0	**2.6**	8.0	5.4	**23.3**	44.3	38.5
Jamaica	**45.0**	46.5	43.1	**10.1**	10.4	8.7	**55.2**	46.5	43.3
Mexico	**59.5**	46.7	44.6	**12.7**	10.8	9.9	**58.9**	52.5	50.2
Nicaragua	**24.6**	40.5	39.8	**2.8**	8.0	7.8	**23.5**	43.6	43.4
Panama	**54.0**	44.6	46.9	**9.5**	10.1	11.3	**59.2**	48.8	51.5
Paraguay	**51.3**	42.8	40.6	**3.4**	9.4	8.3	**49.4**	46.1	43.8
Peru	**45.5**	38.8	38.9	**6.7**	5.2	6.1	**61.6**	45.5	46.6
Suriname	**45.4**	45.5	47.5	**12.9**	10.7	11.6	**47.3**	49.8	51.8
The Bahamas	**80.0**	64.9	61.2	**22.0**	20.4	17.9	**51.3**	69.6	63.0
Trinidad and Tobago	**73.3**	49.7	42.8	**18.9**	12.4	8.8	**46.7**	50.1	42.5
Uruguay	**66.4**	48.9	56.2	**26.8**	12.7	16.1	**101.9**	53.8	61.4
Venezuela, RB*	**60.0**	51.1	28.0	**8.2**	12.9	2.8	**50.5**	58.8	22.8

Source: Authors' estimation and International Telecommunication Union.
*Venezuela's data are constructed for 2015 because of missing information relevant for 2016.

The connectivity level is measured by the internet access indicators described above. Hence, the gap reflects a country's relative position to the expected average connectivity given its structural and institutional endowments. A gap, either positive or negative, also shows a departure from what is financially sustainable or, in other words, from the constrained average level in our set of countries. It is important to highlight that our gap analysis is constrained to coverage and not to quality of internet connectivity indicators; hence, a country can show a positive gap in internet penetration, but have a low quality of service.

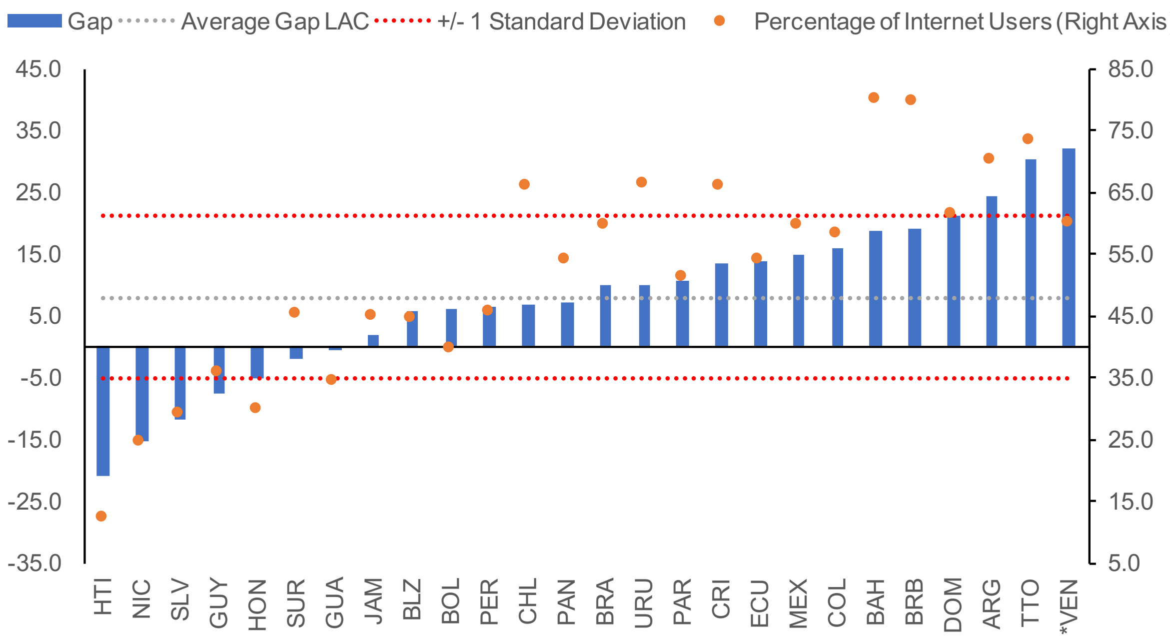
$$Connectivity\_GAP_{it} = Connectivity\_Indicator_{it} - \widehat{Connectivity\_Indicator}_{it} \quad (2)$$

The gap analysis is shown in Figures 3 through 5. These figures illustrate that certain countries consistently have a negative connectivity gap, while others have a positive one. A positive (negative) gap reflects a situation in which the country has a connectivity level above (below) what its institutional and structural characteristics would predict. In these figures, we show the average gap in LAC countries and the one standard deviation from it to highlight the connectivity levels of countries that have significant differences from the benchmark value predicted by our model.

With respect to the connectivity indicators gap, there is substantial variation across LAC countries. Argentina, Uruguay, and Venezuela show consistently positive gaps, while El Salvador, Haiti, Honduras, and Nicaragua exhibit large recurrent negative gaps. In Argentina and Venezuela, for example, their low rule of law and negative business environment perception may explain the significantly positive gap, which would suggest lower sustainable levels of connectivity compared to the currently observed ones. In other words, our model suggests that Venezuela, which had the sixth-lowest score on the Rule of Law indicator in 2016 in the world, exhibits a higher level of internet users than the level that is sustainable according to its current institutional endowments. The same could be said about Argentina, which is among the lowest-scoring countries in the world but has a percentage of internet users closer to that seen in European countries. Another possible explanation is that perhaps public investment with different profitability criteria, such as a subsidy, serves as a stimulus, or public policy provides another incentive. The analysis here does not address the welfare-enhancing nature of these incentives.

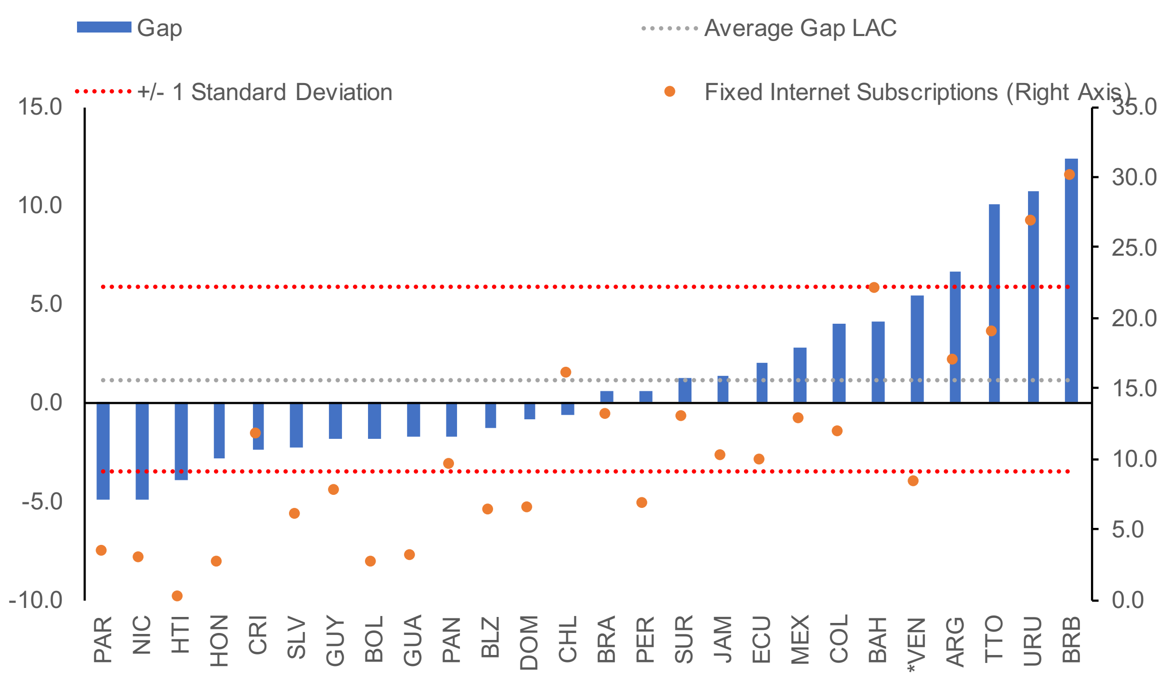
By contrast, the Central American countries and Haiti, which exhibit the largest negative gaps, appear to have an internet penetration lower than what is commercially viable. Although these countries have a low income per capita and weak rule of law, which affect them negatively, their current levels of connectivity are closer to the average of Sub-Saharan African countries, which have even more sluggish fundamentals. Therefore, a policy restriction or other market frictions are expected to be interfering with the capacity of firms to invest in the market.

Figure 3. Percentage of Internet Users Gap



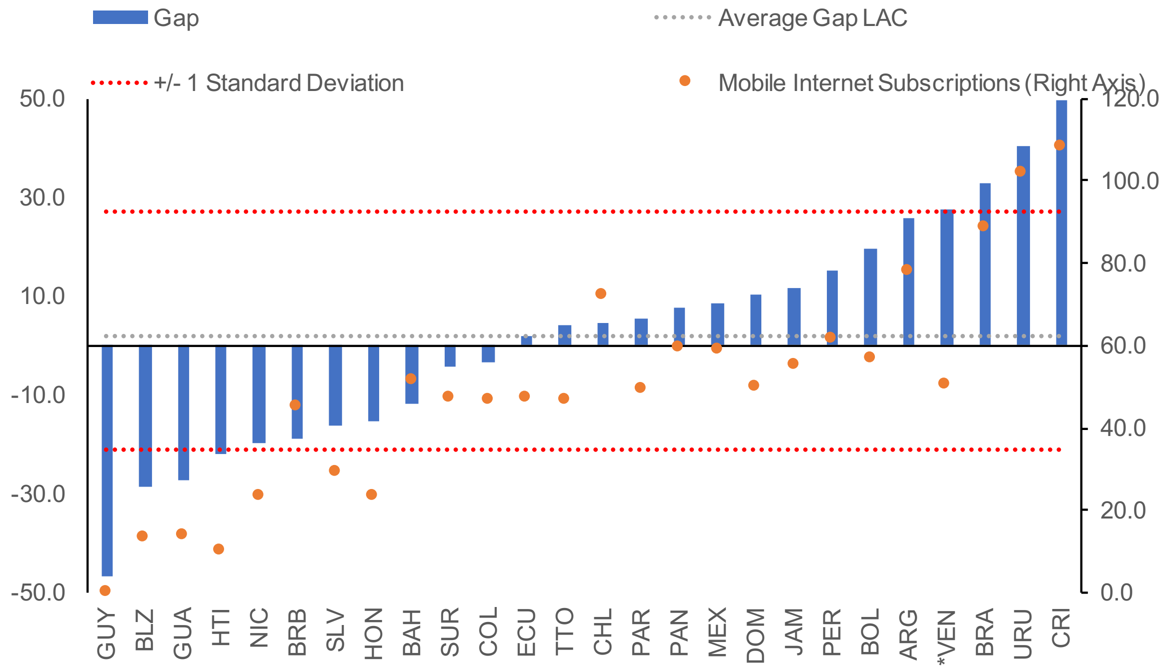
Source: Authors' elaboration.
*Venezuela's data are constructed for 2015 because of missing information relevant for 2016.

Figure 4. Fixed Internet Subscriptions Gap



Source: Authors' elaboration.
*Venezuela's data are constructed for 2015 because of missing information relevant for 2016.

Figure 5. Mobile Internet Subscriptions Gap



Source: Authors' elaboration.
*Venezuela's data are constructed for 2015 because of missing information relevant for 2016.

5. Connectivity Gap Determinants

As a final exercise, we examine the determinants of the connectivity gap. Specifically, we study the relationship between the connectivity gap described in the previous section and the OECD Product Market Regulation Indicators for the telecommunications sector. In these indicators, regulation does not refer to the macro institutional environment or the general regulatory quality, but rather to the more specific regulations of the telecommunications sector. The three indicators used by the OECD are: the entry regulation understood as the rules that restrict the number of entrants in each telecommunication sector; public ownership, which reflects the percentage of shares owned by the government in the largest telecommunications firm in the sector; and the market structure, defined as the number of firms that compete in the same market and the market share of new entrants. All these indicators are measured on a scale from 0 to 6, in which 0 means perfect competition, and 6 reflects a market with no competition.

$$Connectivity\ Gap = \alpha + \beta R_{i,t} + u_{it} \quad (3)$$

Using the model specification given in equation (3), we analyze how entry, public ownership, and market structure affect the connectivity gap. Regression results shown in Table 4 illustrate that public ownership has a negative and significant relationship to all of our connectivity gap indicators. This means that a higher presence of the public sector in the telecommunications market (in the segments of fixed, mobile, and internet providers) is significantly related to lower than expected connectivity levels, which could be capturing inefficiencies in the provision of these services when they are publicly managed. Thus, it should be commercially sustainable to achieve higher levels of connectivity in countries with private sector participation.

Entry is also negative and significant for all our internet gaps, confirming that a market structure with higher costs and barriers to entry can be harmful for competition and thus distance countries from the average level of connectivity. Therefore, a country with fewer restrictions and an open regulation to entrants in the telecommunication sector can be closer to the expected connectivity. Finally, we find that market structure does not have a significant relationship with any of the internet connectivity indicators.

Table 4. Connectivity Gap Determinants

	Internet users gap	Fixed internet gap	Mobile internet gap
Entry	-3.510***	-2.188***	-2.892***
	(0.816)	(0.515)	(2.398)
Public ownership	-2.377***	-1.430***	-5.782***
	(0.387)	(0.226)	(1.005)
Market structure	-0.129	-0.835	1.396
	(1.224)	(0.892)	(3.689)
Observations	533	328	151
R-squared	0.261	0.233	0.149

Source: Authors' estimation.
Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

6. Conclusions

This paper presents the connectivity frontier analysis as an instrument to provide a more accurate benchmarking of connectivity levels across countries and to assess the level of connectivity in a given country. Considering structural and institutional dimensions is key to identifying the underlying factors constraining overall connectivity and assessing the connectivity gap. These factors are related to long-term policy variables that affect investment costs given the inherent characteristics of telecommunications and digital infrastructure (natural monopoly and networks effects). At the same time, we analyze the medium and short-term policy variables to explain the connectivity gap, showing their relationship to the functioning of the telecommunication market, specifically to its entry regulation and the degree of public ownership of the firms participating in the market. As a future line of research, this approach could be extended to other types of infrastructure that share common characteristics with the telecommunication sector (such as the energy sector) to identify the sectors where a country is lagging or is beyond what is expected according to its main structural and institutional characteristics.

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