ESTIMATING THE EFFECTS OF INTERNET EXCHANGE POINTS ON FIXED-BROADBAND SPEED AND LATENCY

*Siope Vakataki ‘Ofa**

The present paper provides estimates of the relationship between the number of Internet exchange points (IXPs) and fixed-broadband speed and latency in 74 countries from 2016 to 2019, using a balanced panel data set developed by the Economist Intelligence Unit for its “Inclusive Internet Index”. While in several studies, a positive role of IXPs on Internet speed and latency is established, a majority of the earlier ones are technical studies examining the traffic routes in specific networks. This paper contributes to this literature by triangulating earlier findings using an econometric model. The recent availability of the panel data set on IXPs, speed and latency by the Economist Intelligence Unit has made this exercise possible.

The preliminary findings highlighted a statistically significant and positive relationship between the number of IXPs and fixed-broadband speed. For every 1 per cent increase in the number of IXPs per 10 million inhabitants, the fixed-broadband download speed (Kbps) is expected to increase by approximately 0.8 per cent. Despite the benefits of IXPs, challenges remain in establishing them, and collaboration and trust among several stakeholders (national and international) is required. These challenges pose important policy implications for policymakers in ensuring the sustainability of IXPs.

JEL classification: L96

Keywords: Internet exchange point, Internet speed and latency, panel data set, Asia and the Pacific

---

* Siope Vakataki ‘Ofa, ICT and Development Section, ICT and Disaster Risk Reduction Division, United Nations Economic and Social Commission for Asia and the Pacific, Bangkok. An earlier version of the paper benefited from useful comments from the participants of the Pacific Working Group on “Strengthening efficient Internet traffic management through a subregional Internet exchange point (IXP) in Pacific Island countries”, held in Suva, from 3 to 5 December 2019. In addition, external ICT experts and two anonymous reviewers provided useful inputs. The views expressed in this paper are those of the author and should not necessarily be considered as reflecting the views or carrying the endorsement of the United Nations. All errors and omissions are the author’s sole responsibility.

I. INTRODUCTION

Access to the Internet contributes to socioeconomic development (Grace and others, 2004; Qiang, Pitt and Ayers, 2004; ITU, 2012; Minges, 2015; Lubis and Febrianty, 2018, among others). However, access to affordable and reliable broadband connectivity is not universal and particularly challenging in countries with special needs (least developed countries, landlocked developing countries and small island developing States).

According to the information and communications technology (ICT) statistics from the Inclusive Internet Index 2020[1] of the Economist Intelligence Unit on fixed-broadband access, speed (Kbps), latency[2] (ms), and the affordability,[3] the average access to fixed and mobile broadband subscriptions are the highest in high-income countries (33 per cent and 121 per cent, respectively), compared to low-income countries (2 per cent and 88 per cent, respectively). ESCAP (2016; 2017) highlighted the widening digital divide, not only by income but also by geographic region. The average monthly fixed-broadband upload (36,127 Kbps) and download (64,112 Kbps) speeds are the highest in high-income countries, compared to lower Internet speeds in low-income countries (13,005 Kbps and 14,521 Kbps, respectively).

Latency on fixed-broadband (31 ms) and mobile-broadband (51 ms) are, on average, lower in high-income countries compared to low-income countries (45 ms and 82 ms, respectively). On average, fixed-broadband (1 per cent)[4] and mobile-broadband services (0.7 per cent) are affordable in high-income countries, compared to low-income countries (13 per cent and 2 per cent, respectively). ESCAP and National Information Society Agency (2016, p. 33) measured the Internet speed and traffic in CLMV (Cambodia, the Lao People's Democratic Republic, Myanmar, and Viet Nam) countries and highlighted that most of the international traffic of these countries have been exchanged outside the region (in North America or Europe).

---

1 Economist Intelligence Unit, Internet Inclusive Index webpage (https://theinclusiveinternet.eiu.com/).

2 Delay it takes to send information from one point to another in milliseconds (ms).

3 Monthly expenditure on broadband services as a percentage of gross national income per capita.

4 According to the United Nations Broadband Commission, a target of broadband services should be made affordable in developing countries at less than 2 per cent of monthly gross national income per capita by 2025. For further details, refer to www.broadbandcommission.org/broadband-targets/.

A national Internet exchange point (IXP) facilitates access of users to online services and improves the affordability and quality of Internet services. It is a physical location where different Internet provider networks connect to exchange traffic with each other using a copper or fibre-optic cable through one or more Ethernet switches or servers (Internet Society, 2014, p. 6). The key role of a national IXP is to improve the national Internet traffic network performance (Internet speed in Kbps and latency – delay it takes to send digital information[5] from one point to another in milliseconds (ms), by keeping local Internet traffic local and to reduce the costs (transit price (US$/Mbps)) associated with traffic exchange between networks.

A national IXP significantly improves the efficiency of Internet traffic, resulting in cost savings. This is made possible by eliminating the routing of Internet traffic through expensive long-distance traffic routes outside the country before returning back to the country. Consolidating national traffic from different networks significantly improves national Internet traffic network management and eliminates the need for multiple physical links between local network operators and international operators. In addition, download speed for websites improves significantly, thereby encouraging the development of new local content and services and providing opportunities for productive use of Internet for other purposes (for example, e-commerce or e-government services).[6]

Past research literature (mostly from the technology side) has pointed to the positive effects of IXPs on improving Internet speed and latency. After testing the latency of Internet traffic going through IXPs, Ahmad and Guha (2012, p. 10) found that the traffic encountered lesser delays than normal links, even though the presence of IXPs did not decrease the length of an Internet network path. Galperin (2013, p. 21) analysed IXPs in Latin America and the Caribbean and concluded that they reduced access costs, increased Internet quality, encouraged infrastructure investments in isolated communities and promoted knowledge transfer. Indeed, policymakers in Latin America and the Caribbean, as well as in Africa, recognize the important role of IXPs as a national asset with clear benefits to a country's Internet network architecture (ITU, 2013a, p. 18; 2013b, p. 37).

[5] For example, if one person sends an email (digital information) from Bangkok to another person in Chiang Mai (within Thailand), the delay (measured in milliseconds) that takes for the digital information (email) to be received by the person in Chiang Mai is affected by the presence of a national Internet exchange point.

[6] For a discussion on the benefits of IXPs, refer to Internet Society (2014).

Internet Society (2015, p. 2) noted the benefits of IXPs:

(a) Lowers Internet-access costs for end users by decreasing Internet service provider (ISP) operating costs and making Internet access more affordable for a greater number of local Internet users in a country or region;

(b) Ensures that Internet traffic between local senders and local recipients use cheap local connections, rather than expensive international links. In some countries, up to 20 per cent of local Internet traffic can make up a significant portion of the overall Internet traffic of an ISP;

(c) Creates efficient interconnection points that encourage network operators to connect in the same location in search of beneficial peering arrangements, cheaper and better traffic exchange, and other information and communication services;

(d) Attracts out-of-country service operators. A single connection to an IXP provides out-of-country service operators with lower collective access costs to multiple potential local customers;

(e) Contributes to the development of the local Internet ecosystem and local service hosting/local content development. An IXP creates a local environment that attracts a variety of other services, including domain name servers and content and web caches;

(f) Improves local users' quality of access by providing more-direct network connections for local content producers and consumers;

(g) Enhances the level of stability and continuity of access, namely the IXP switching, capability by providing additional flexibility in redirecting Internet traffic when there are connectivity problems on the network. For example, if there is a breakdown in international connectivity, an IXP can keep local traffic flowing within the country;

(h) Internet exchange points are not expensive to establish. The cost of the equipment required to establish an IXP is usually minimal, making the establishment of an IXP an affordable local project. Under a sustainable funding and management model, ISPs and other network operators, which benefit from using IXPs, can often cover the initial start-up and monthly operating costs.

ESCAP and National Information Society Agency (2016, p. 54) highlighted that IXPs should be designed to identify the best way to connect traffic routes to each destination. In particular, IXPs should be neutral and open to any operator. In addition, they stressed that all stakeholders should be involved in the establishment of IXPs to agree on a common principle on the traffic management. The principle may include the following: the requirement for exchanging of routing information with all Internet service providers connected to the IXPs; and the need to establish a neutral organization capable of operating and managing IXPs.

While recognizing the technical benefits of IXPs, establishing one, especially when it involves operators from several countries to connect, is not clear cut. Many IXPs are set up for public service (non-commercial reasons), requiring the collaboration of all ISPs in a country. However, its subsequent success relies on the willingness of ISPs to cooperate and connect their respective traffic through a common IXP. In many cases, these ISPs are often competitors with each other. Accordingly, a great deal of time and resources are required to consolidate and build trust among several actors who may be competitors in a market. This challenge is further complicated when ISPs from several countries need to agree on interconnection through a common IXP.

Other challenges on establishing an IXP are the difficulty in establishing (a) a neutral physical location and operation of an IXP which is agreed upon by all IXP parties and is not in a government office or private sector facility and (b) a neutral operation/governance by a non-governmental organization not linked to government or a private sector (Internet service provider).

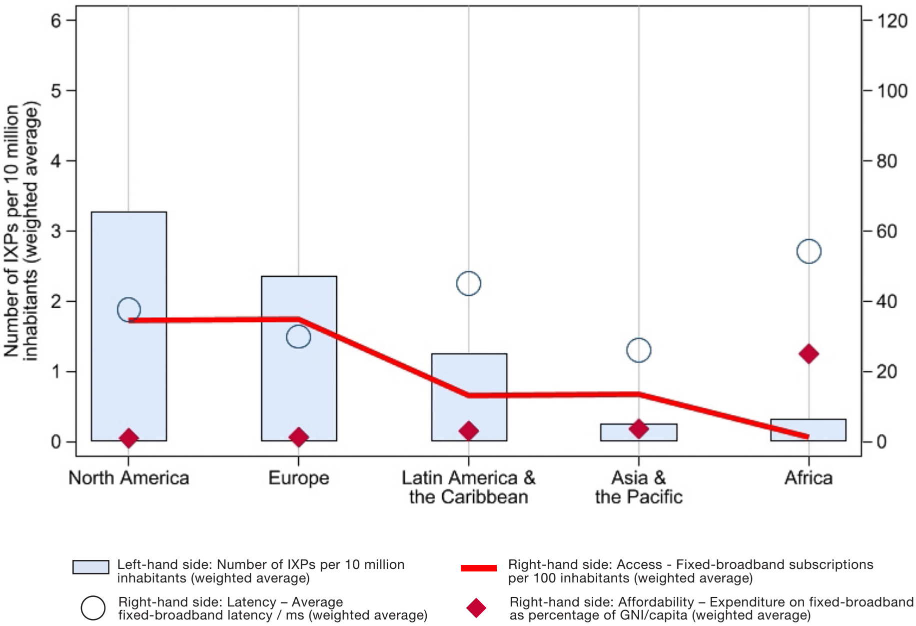
II. INTERNET EXCHANGE POINT (IXP) TRENDS

National IXPs have been deployed in many countries around the world. North America (driven by the United States of America) and Europe are the two major regions with the highest number of IXPs per 10 million inhabitants.[7] This is followed by Latin America and the Caribbean, Asia and the Pacific, and Africa (see figure 1). The development of IXPs is also prevalent in high-income countries, as compared to low-income countries (see figure 2). As a result, the development of IXPs (per 10 million inhabitants)[8] are severely lacking in the low-income countries of Africa, and Asia and the Pacific.

[7] Further discussion on this variable reported by the Inclusive Internet Index database (https://theinclusiveinternet.eiu.com/) of the Economist Intelligence Unit, for better reflection of the level of IXPs within countries/regions, is in the next section.

[8] The conversion of the raw number of IXPs into a rate (per 10 million inhabitants) for each country allows for comparison across countries. In general, the greater the population (or population rate in 10 million inhabitants) of a country, the more market (or potential) to be served, the more ISPs are present to benefit from such a large market, and the more need for IXPs to be established to ensure Internet efficiency.

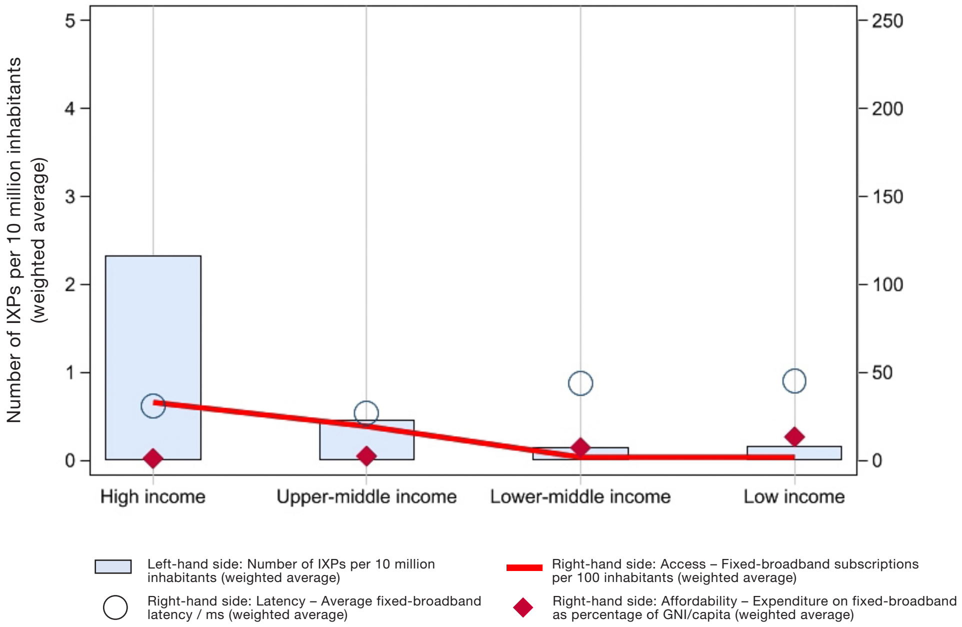
Figure 1. Internet exchange points by major regions



Source: Economist Intelligence Unit, Inclusive Internet Index 2020 database. Available at https://theinclusiveinternet.eiu.com/ (accessed on 27 February 2020).

For a better understanding on the role of IXPs and the efficiency of fixed-broadband speed and latency in countries across the world, IXP developments can be assessed against broadband efficiency indicators, namely access to fixed-broadband and its latency and affordability. When the trend on access to fixed-broadband subscriptions per 100 inhabitants is compared against the IXP trend for major regions, a similar pattern follows. This is, access to fixed-broadband subscription is higher in North America and Europe, as compared to Asia and the Pacific, and Africa. This pattern is also found across different countries' income-levels (figure 2). High-income countries with the highest number of IXPs (per 10 million inhabitants) have experienced the highest access to fixed-broadband subscription. On the other hand, low-income countries with the lowest access to fixed-broadband subscription experienced the lowest number of IXPs.

Figure 2. Internet exchange points by income group



Source: Economist Intelligence Unit, Inclusive Internet Index database. Available at https://theinclusiveinternet.eiu.com/ (accessed on 27 February 2020).

Affordability (monthly expenditure on fixed broadband as a percentage of gross national income per capita)[9] of fixed-broadband subscription is the lowest (very affordable) in high-income countries, as compared to low-income countries (figure 2). A majority of these low-income countries are in Africa, and Asia and the Pacific, while affordable fixed-broadband subscriptions are available in North America and Europe.

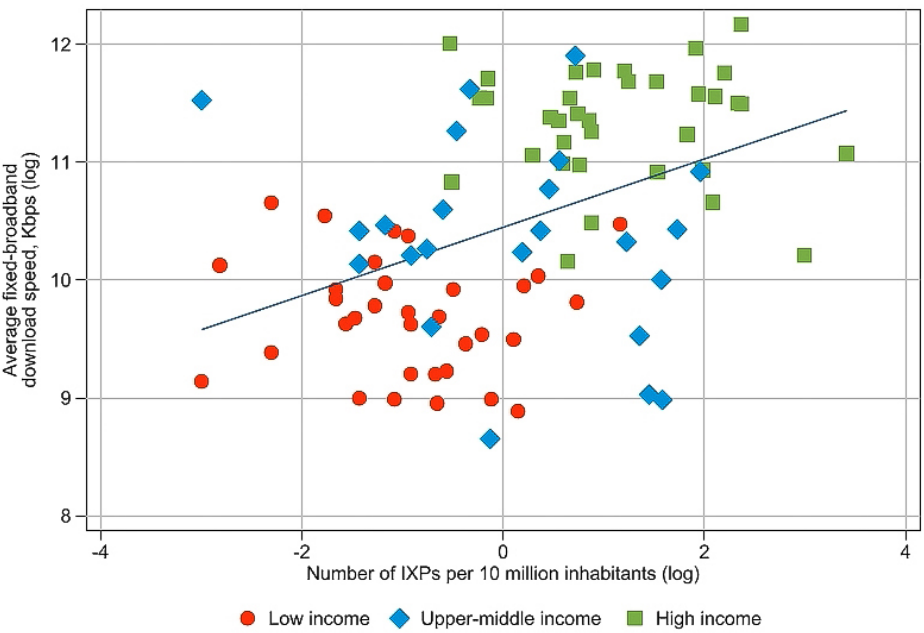
At the country level, the number of IXPs per 10 million inhabitants varies significantly among countries (see annex figure A.1). The top 10 countries with the highest number of IXPs per 10 million inhabitants are Estonia, Bahrain, Lithuania, Singapore, Latvia, Sweden, New Zealand, Australia, Trinidad and Tobago, and Bulgaria. The majority (four countries) of them are in Europe, followed by the Asia-Pacific region (three countries). The 10 countries with the lowest IXPs per 10 million inhabitants are Algeria,

9 The United Nations Broadband Commission considers a target of less than 2 per cent as affordable.

Azerbaijan, El Salvador, Ethiopia, Guatemala, Nicaragua, Oman, Venezuela, Qatar and China. The majority of these countries (four) are in South America, followed by Africa (two) and Asia (two). The IXP variable is, therefore, a useful indicator for producing a holistic picture of the development of IXPs in each country.

In terms of fixed-broadband speed (upload and download, Kbps), speed is faster in high-income countries, as compared to low-income countries (see figures 2 and 3). High-income countries have invested more on modern ICT infrastructure connectivity, resulting in faster fixed-broadband speed.

Figure 3. Fixed-broadband speed (Kbps)



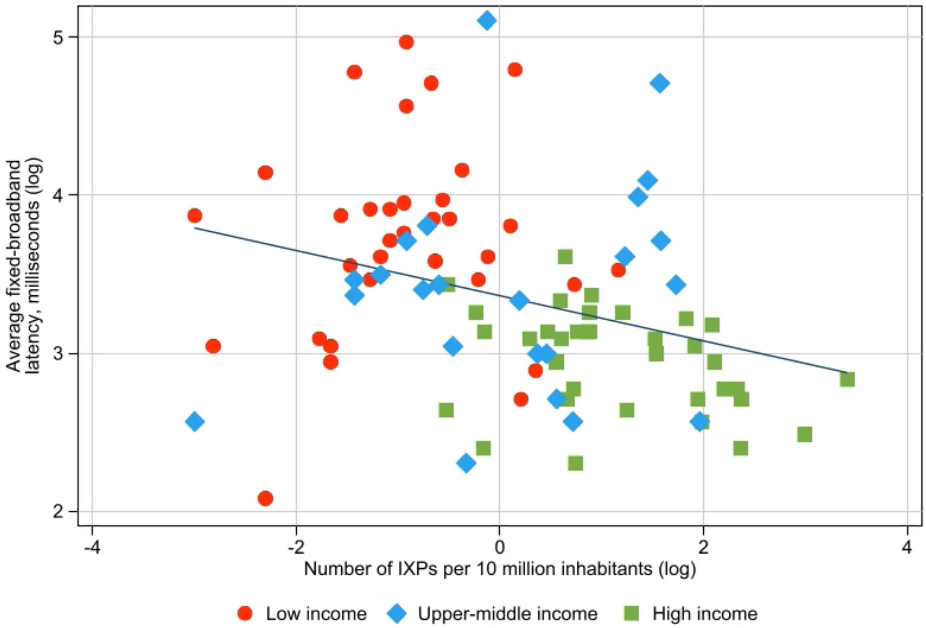
Source: Economist Intelligence Unit, Inclusive Internet Index 2020 database. Available at https://theinclusiveinternet.eiu.com/ (accessed on 27 February 2020).

On the other hand, low-income countries have less advanced ICT infrastructure connectivity and as a result, fixed-broadband speed is low. This trend is consistent on both connectivity technologies (mobile-broadband and fixed-broadband) commonly used for communications.

The latency (ms) trend shows a reverse relationship with the IXP trend. This is, high-income countries have the lowest Internet latency, as compared to the low-income countries, which tend to have the highest Internet latency (figures 2 and 4). Similarly, at the region level, Africa has a lower number of IXPs and a higher Internet latency compared to North America and Europe.

There are similar trends related to fixed-broadband latency (ms); shorter delays were experienced in networks of high-income countries compared to low-income countries in 2020 (figure 4). Fixed-broadband latency (ms) is a complex challenge with multidimensional causes. Zaki and others (2014, p. 244) highlighted that slow Internet in developing countries was due to geographic locations (further distances create higher latency); infrastructure challenges (low bandwidth links and high network contents); and routing problems (inefficient protocols and architectural issues, such as content distribution networks server placement).

Figure 4. Fixed-broadband latency (ms)



Source: Economist Intelligence Unit, Inclusive Internet Index 2020 database. Available at https://theinclusiveinternet.eiu.com/ (accessed on 27 February 2020).

According to the Inclusive Internet Index 2020 statistics, the average latency (ms) on fixed-broadband subscriptions is the highest in Africa (56 ms), followed by Latin America and the Caribbean (38 ms), North America (25 ms), Europe (22 ms) and Asia and the Pacific (21 ms). As for broadband subscriptions, latency is the shortest in Europe (39 ms), North America (49 ms), Asia and the Pacific (48 ms), Latin America and the Caribbean (51 ms), and Africa (52 ms). Africa is the major group with highest delays on broadband subscriptions. In addition, latency (ms) is lowest in fixed-broadband technology compared to mobile-broadband technology.

In summary, the development of IXPs is prominent in higher-income countries and vice versa. In addition, countries with a higher number of IXPs per 10 million inhabitants also tend to have greater access to broadband subscriptions, less broadband latency, and more affordable broadband. These trends raise important policy questions about the role of IXPs on fixed-broadband efficiency (in terms of latency and speed), particularly, in countries where IXPs are predominantly missing, namely low-income countries with less access to broadband Internet, higher latency, and unaffordable broadband access).

III. ANALYTICAL FRAMEWORK

The literatures from technology and communications discussed in an earlier section point to a positive relationship between the presence of an IXP and efficiency of Internet traffic in countries. Most of these studies are technical and focus on assessing the relationship between the two variables using national surveys or online tools to measure traffic routes. Limited attention, however, has been given to statistically evaluating this relationship. In this present paper, attempts were made to fill that gap by empirically testing the relationship between the number of national IXPs and fixed-broadband speed and latency.

Accordingly, in the present paper, the efficiency (speed and latency) of fixed-broadband traffic flow exchanged between different ISPs within a country improve, namely speed increases result in a decrease in latency as the number of IXPs increases is hypothesized. The hypothesized relationships between the main independent and dependent variables are summarized in table 1.

Table 1. Main independent and dependent variables

Independent variable	Dependent variables
Presence of Internet exchange points	**Efficient fixed-broadband traffic flow**
Quantitative measures: • Number of IXPs per 10 million inhabitants (+)	Quantitative measures: • Fixed-broadband download speed (Kbps) (+) • Latency (fixed-broadband latency) (average, ms) (-)

Source: Author's consolidation.

Notes: (+) positive correlation (increasing); (-) negative correlation (decreasing).

The relationships between the efficiency (speed and latency) of fixed-broadband and the number of IXPs assume the following model specification:

$$FixBroEff_{i,t} = \alpha_i + \beta_1 Ixp_{i,t} + \beta_2 FixBro_{i,t} + \beta_3 CabSta_{i,t} + \beta_4 NetCov_{i,t} + \beta_5 NeuPol_{i,t} + \beta_6 Gdp_{i,t} + \beta_7 Pop_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$i = 1, 2, \ldots, N;\ t = 1, 2, \ldots, T,$$

where $FixBroEff_{i,t}$ is the natural logarithm of the efficiency of fixed-broadband speed (Dep. Var 1) and latency (Dep. Var 2) in country i at time t. The coefficient α_i is the unknown intercept for country i, while $\varepsilon_{i,t}$ is the error term representing the effect of the variables that were omitted by the model in country i at year t. The number of countries included are N = 74 countries with number of time-series T = 4 years. $Ixp_{i,t}$ is the independent variable (natural logarithm of number of IXPs per 10 million inhabitants) in country i in year t. It is, therefore, expected that an increase in the number of IXPs is also associated with an improvement in efficient fixed-broadband traffic flow (positive correlation with speed, and negative correlation with latency).

As discussed in the previous section, the presence of the independent variable (number of IXPs per 10 million inhabitants) is common in higher-income countries. In addition, countries with higher IXPs also tend to have higher fixed-broadband access, lower latency and more affordable broadband access.

Other control variables are the log-transformed[10] of the following: access to fixed-broadband subscriptions per 100 inhabitants (*FixBro*); cross-border connectivity – number of cable landing stations per 10 million inhabitants (*CabSta*); last-mile ICT infrastructure connectivity – percentage of population covered by 3G network; (*NetCov*); economic development – GDP (US$ billions) (*Gdp*); and market size – population (millions) (*Pop*). In addition, a technology-neutrality policy for spectrum use – qualitative rating (0-1, 1 = best) (*NeuPol*), was used to control for the sector's policy environment.

Relationships between dependent, independent and control variables were tested using the fixed effects method. Baltagi (2005, p. 1) best captured the benefits of fixed effects by highlighting that the fixed-effects method is effective when the question of interest controls for individual heterogeneity (variable that changes over time but not across entities). Baltagi (2005, p. 4) further stated that panel data give more information, more variability, less collinearity among variables, more degrees of freedom, and more efficiency in estimation. In addition, panel data are more effective in identifying and measuring the effects that are not detectable in non-panel structured data sets. However, Baltagi (2005, p. 13) also highlighted the limitations of the fixed-effects method linked to the collection of data for the panel data set (problems with designing and data collection, missing observation and high costs of data collection).

With respect to the appropriateness of the use of fixed-effect method, the Sargan-Hansen statistics[11] had rejected the null hypothesis that the errors are correlated with the exogenous variables in the model, and therefore, the fixed-effect method is the preferred method. The modified Wald test[12] indicated the presence of heteroskedasticity, and accordingly, the Huber/White estimator was used to obtain heteroskedasticity-robust standard errors.

An objective of this paper is to assess the relationship between IXPs and fixed-broadband speed and latency in 74 countries between 2016 and 2019. The fixed-effect method is, therefore, ideal in analysing the impact of a particular variable that varies over time. In addition, the fixed-effect method controls for any potential correlation within the country and between the independent/dependent variables that may render the estimation bias, by removing the effect of those time-invariant biases.[13]

[10] Variables' distributions were not symmetric, hence the need for log-transformation.

[11] Sargan-Hansen statistic = 18.523, Chi-sq(7), P-value = 0.009.

[12] Modified Wald test chi2(85) = 9.5, Prob>chi2 = 0.0000.

[13] For further details, refer to Baltagi (2005).

IV. DATA

For this paper, a balanced short panel of 74 countries from 2016 to 2019 is used. The panel data set was developed and maintained by the Economist Intelligence Unit (EIU), for computing the Inclusive Internet Index.[14]

The Inclusive Internet Index is comprised of 53 indicators categorized under four key areas: availability, affordability, relevance, and readiness. “Availability” consolidates the scores from indicators that measures the quality and depth of infrastructure for access, including Internet use, the quality of the Internet connection, and the type and quality of infrastructure available for Internet and electricity access. “Affordability” consolidates scores on indicators for cost of access relative to income level and competition in the ICT market. “Relevance” looks at the existence and extent of local language content. This key area measures the perceptions on the value of being connected to the Internet by users in terms of useful local contents and services. “Readiness” measures the capacity of users to take advantage of access to the Internet for productive use.

Each of the four key areas receives a score calculated from a weighted average of the underlying indicator scores and then scaled from 0 to 100 (100 indicates the highest/strongest). The overall country score (adjusted) is a weighted average of the four key areas’ scores. Further details on the methodology for calculating the Index can be accessed from the Methodology Report.[15] Variables categorized under each key area are listed in table 2. A list of all variables is shown in annex table A.1.

[14] The Economist Intelligence Unit (EIU), The Inclusive Internet Index 2019. Available at https://theinclusiveinternet.eiu.com (accessed on 28 October 2020).

[15] Ibid.

Table 2. The Inclusive Internet Index 2019 – key areas of focus

1. Availability (20)	2. Affordability (7)	3. Relevance (10)	4. Readiness (21)	Background variables (25)
1.1. Usage (5)	2.1. Price (4)	3.1. Local content (3)	4.1. Literacy (4)	Social, economic & political variables (25)
1.2. Quality (7)	2.2. Competitive environment (3)	3.2. Relevant content (7)	4.2. Trust & safety (6)	
1.3. Infrastructure (6)			4.3. Policy (11)	
1.4. Electricity (2)				

Source: Author's consolidation based on the Economist Intelligence Unit (EIU), The Inclusive Internet Index 2019. Available at https://theinclusiveinternet.eiu.com (accessed on 28 October 2019).

Note: Numbers in brackets show the number of variables under each category and subcategory.

The data set is extremely useful for this study, as it is the first of its kind to collect statistics for most countries (100 countries in the 2020 version) on the number of IXPs per 10 million inhabitants on a yearly basis, allowing for a format that can be used for econometric testing. While the International Telecommunications Union (ITU) collects most of the ICT statistics through its annual World Telecommunication/ICT Indicators database,[16] it does not include statistics on IXPs.

Other credible data sets with ICT indicators, such as World Development Indicators from the World Bank[17] and the Networked Readiness Index from the World Economic Forum,[18] do not collect statistics on the number of IXPs per population. While many online platforms, such as the TeleGeography Internet Exchange Map,[19] and the Internet Society IXP platform,[20] provide statistics on the number of IXPs in each

[16] ITU, World Telecommunication/ICT Indicators database. Available at www.itu.int/en/publications/ITU-D/pages/publications.aspx?parent=D-IND-WTID.OL-2019&media=electronic (accessed on 28 October 2019).

[17] World Bank, World Development Indicators. Available at https://data.worldbank.org/ (accessed on 28 October 2019).

[18] World Economic Forum, Networked Readiness Index. Available at http://reports.weforum.org/global-information-technology-report-2016/networked-readiness-index/?doing_wp_cron=1572941503.7552540302276611328125 (accessed on 28 October 2019).

[19] TeleGeography, Internet Exchange Map. Available at www.internetexchangemap.com/ (accessed on 28 October 2019).

[20] Internet Society, IXP platform. Available at www.internetsociety.org/issues/ixps/ (accessed on 28 October 2019).

country. These online sources do not provide panel data with changes on a yearly basis, namely on how many IXPs are established in each country every year.

In addition, the Inclusive Internet Index data set collects statistics on other policy variables that allows for testing of fixed-broadband speed and latency and other interesting policy variables for future research, such as Internet affordability, local content, trust and safety, policies on female e-inclusion, female STEM education, spectrum policy and national digital identification policy.

Limitations of the Inclusive Internet Index data set however are the following.

First, as the data set is relatively new (2016–2019), it provides limited observations for a stable estimation result. Consequently, the results of this paper may need to be revisited in three to five years to allow for additional years with observations in the estimation. Nunnally and Bernstein (1967) suggested that in multiple regression modelling, for each independent variable (X), there should be at least 10 observations (namely for $Y = B_0 = B_1X_1 + B_2X_2$, then there should be 10 observations for X_1, and 10 observations for X_2, and 10 observations for Y, or total of 30 observations). In the case of the estimation in this paper, there are seven variables (excluding the constant) with observations of around 189 (double the acceptable level).

Second, the 2020 version of the data set only included 100 countries with several least developed countries, landlocked developing countries and small island developing States noticeably missing.[21] However, the countries that are included represent well the global trend thought the inclusion of the ten largest economies in the world: the United States, China, Japan, Germany, the United Kingdom, India, France, Brazil, Italy and Canada. By population, more than 75 per cent of the world's population are controlled for with the inclusion of major populous countries, such as China, India, the United States, Indonesia, Brazil, Pakistan, Nigeria, Bangladesh, the Russian Federation and Mexico. As a result, the overall results of the estimations generated from the paper are indeed representative of the global trend.

[21] Controlling for smaller countries in the data set is also a challenge considering that the variable required for computing a new control variable (such as one million per inhabitants) for smaller countries is not available at the Economic Intelligence Unit data set. This missing variable is the number of IXPs established in each of the years.

V. RESULTS

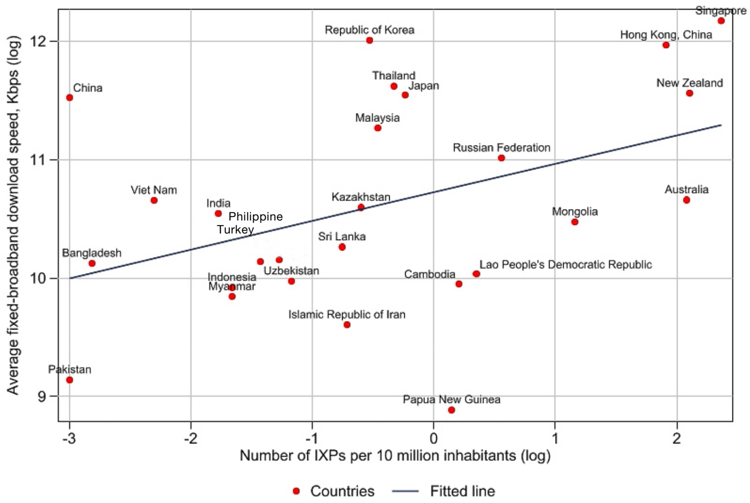
The relationship between the number of IXPs per 10 million inhabitants and fixed-broadband speed and latency, was first checked using a simple scatter plot. When assessed by geographic regions, a positive correlation between IXPs and fixed-broadband speed was found, while there appears to be a negative correlation between IXPs and fixed-broadband latency for Asia and the Pacific (figure 5).

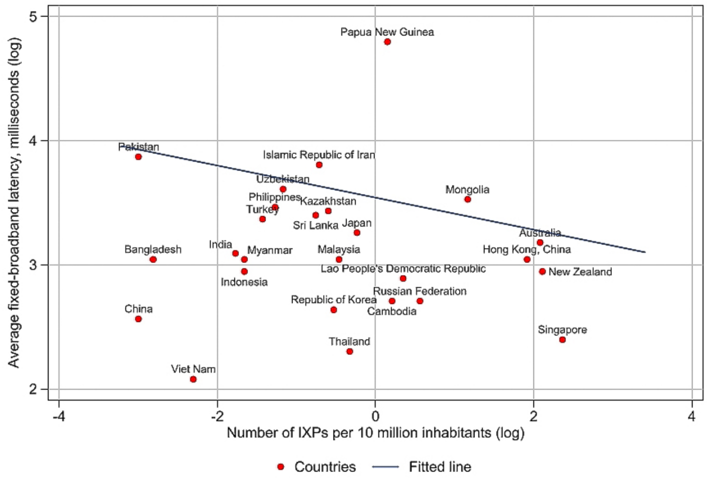
Singapore and Australia, are among the leading countries with high fixed-broadband speed and number of IXPs per 10 inhabitants (figure 5). Similarly, Singapore and Australia are the leading countries with the lowest fixed-broadband latency.

In the case of Europe, a similar IXP correlation pattern is found with respect to fixed-broadband speed and latency (annex figure A.2). Estonia and Lithuania are the leading countries in Europe for high fixed-broadband speed and number of IXPs per 10 inhabitants. Similarly, Estonia and Lithuania are the leading countries with the lowest fixed-broadband latency.

Moving on to Latin America and the Caribbean, a similar pattern is found with a positive correlation between the number of IXPs and fixed-broadband speed, while negatively correlated with fixed-broadband latency. Argentina, and Trinidad and Tobago are the two leading countries with respect to positive correlation between the number of IXPs and fixed-broadband speed, while negatively correlated with fixed-broadband latency (annex figure A.3). A similar pattern is also found for Africa (annex figure A.4).

Figure 5. Internet exchange points versus fixed-broadband speed and latency (Asia-Pacific region)





Source: Economist Intelligence Unit, Inclusive Internet Index 2020 database. Available at https://theinclusiveinternet.eiu.com/ (accessed on 27 February 2020).

Note: IXPs: Internet exchange points.

The relationship between the number of IXPs and fixed-broadband speed and latency was further assessed through an econometric model that controls for the effects of other variables. The results of the fixed-effects method are presented in table 4.

The results of the fixed-effects estimation indicate that the number of IXPs per 10 million inhabitants is positively correlated and statistically significant with fixed-broadband download speed (Kbps) (Dep. Var 1). In other words, for every 1 per cent increase in the number of IXPs per 10 inhabitants, the speed of fixed-broadband download speed (Kbps) is associated with an increase by approximately 0.8 per cent.[22]

In addition, the results indicate that the number of IXPs per 10 million inhabitants is statistically significant and negatively correlated with fixed-broadband latency (ms) (Dep. Var 2). For every 1 per cent increase in the number of IXPs per 10 inhabitants, fixed-broadband latency (ms) is associated with a decrease of approximately 0.4 per cent. Overall, the preliminary results from the fixed-effects estimation provide empirical evidence to support the important role of IXPs in improving fixed-broadband speed and latency in countries.

The remaining control variables behaved as expected. The fitness of the estimate for fixed-broadband speed (Dep. Var 1) and fixed-broadband latency (Dep. Var 2) are fairly robust, as indicated by the statistical significance of many control variables. With regard to the access of subscribers to fixed-broadband services ($FixBro$), a positive relationship is found between an increase in access to fixed-broadband services and an increase in fixed-broadband speed. On the other hand, an increase in access to fixed-broadband services is associated with a decrease in fixed-broadband latency (ms). This finding is aligned with the literature on digital divide in such countries as Australia, Japan, the Republic of Korea and Singapore, which showed a very high rate of access to fixed-broadband Internet and higher fixed-broadband speed and lower latency (ms), compared to low-income countries.

When controlling for the level of cross-border connectivity[23] in each country, the number of cable landing stations per 10 million inhabitants ($CabSta$) shows a positive and statistically significant relationship with fixed-broadband speed (Kbps), and negative correlation with fixed-broadband latency. The more cable landing stations per population, the better and more stable the fixed-broadband connection will be;

---

[22] Or for every 10 per cent increase in the number of IXPs per 10 inhabitants, it is associated with a fixed download speed (Kbps) increase of about $(1.10^{0.8} - 1) * 100 = 8$ per cent.

[23] Considering that more than 70 per cent of global Internet traffic are routed through fibre-optic cables.

this provides a strong foundation for increased fixed-broadband speed. In addition, the increasing number of cable stations also demonstrates a country's resilience to natural disasters. In particular, if one cable is broken due to a natural disaster, the second cable could provide the broadband lifeline to the country. Access to multiple cable stations (multiple cross-border fibre cables) implies higher chances of being able to connect to more efficient shorter traffic routes, which can improve fixed-broadband latency.

Table 4. Fixed-effects estimation results

Independent variables	**Dep. Var 1 Fixed-broadband download speed - Kbps (log)**	**Dep. Var 2 Fixed-broadband latency (avg, ms) (log)**
Number of Internet exchange points per 10 million inhabitants (log)	**0.773*** (0.125)**	**-0.319*** (0.0722)**
Fixed-broadband subscribers per 100 inhabitants (log)	0.557*** (0.162)	-0.408*** (0.129)
Number of fibre-optic cable landing stations per 10 million inhabitants (log)	0.499*** (0.136)	-0.266*** (0.0820)
Percentage of population covered by 3G network (Log)	0.435 (0.370)	0.236 (0.182)
Technology-neutrality policy for spectrum use; qualitative rating 0-1, (1 = best)	0.242 (0.152)	-0.135 (0.0877)
GDP, US$ billions (log)	2.028*** (0.345)	-0.858*** (0.145)
Population, millions (log)	7.052*** (1.000)	-1.250** (0.562)
Constant	-29.49*** (4.515)	12.73*** (2.621)
Observations	189	189
R-squared (within)	0.697	0.501
Number of countries	74	74

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Last-mile broadband infrastructure connectivity as a percentage of population covered by 3G mobile network (*NetCov*), is positively correlated with fixed-broadband speed and negatively correlated with fixed-broadband latency (ms). Both coefficients are statistically significant. This result is in line with existing literature on private investment in broadband infrastructure. When investment and deployment of 3G network infrastructure increases to cover most of the population, a business case is, therefore, warranted for network operators to provide efficient Internet traffic to current and new customers for generating higher revenue.

ICT conducive policy, proxied by the quality[24] of technology-neutrality policy for spectrum use) (*NeuPol*), was used to control for the sector's policy environment although no statistically significant results came out from the model. GDP (US$ billions) (*Gdp*) is a proxy for income levels in countries. A positive and statistically significant relationship is found between the income level of countries and Internet speed. Higher-income countries also experience higher Internet speed. This finding is aligned with earlier studies by ESCAP (2016, p. 13; 2017, p. 72) in which population (millions) (*Pop*) was used as a proxy of country/market size. A positive relationship[25] was found with fixed-broadband speed, while a negative relationship was found with fixed-broadband latency. This finding suggests the presence of economies of scale. In particular, as market size increases, demand for Internet services which incentivizes network operators to invest in improving Internet speed and latency increases.

VI. CONCLUSION AND POLICY IMPLICATIONS

The preliminary findings of this paper provide econometric evidence towards the important role of IXPs in improving fixed-broadband speed and latency. In particular, the number of IXPs per 10 million inhabitants is positively correlated and statistically significant with fixed-broadband download speed (Kbps). For every 1 per cent increase in the number of IXPs per 10 million inhabitants, the speed of fixed-broadband download (Kbps) is associated with an increase of 0.8 per cent. In addition, the presence of IXPs is common in high-income countries and vice versa. Countries with a higher number of IXPs also tend to have greater access to broadband Internet,[26] and the costs are more affordable.

Despite the benefits of IXPs, challenges remain on establishing IXPs. In particular, the need for collaboration and building trust between several stakeholders (national and international), a neutral location and management of IXPs as a platform for all

[24] Qualitative rating (0-1, 1 = best).

[25] Statistically significant in both cases.

[26] Mobile service providers will play an increasingly important role going forward, with the transitioning from 4G to 5G.

operators to connect and a conducive regulatory environment that supports an open market for telecommunication services.[27]

As a result, these challenges pose three important policy implications for policymakers in ensuring the sustainability of IXPs. First, strong political support is needed. Governments that champion the process need to ensure that existing and new regulatory policies facilitate an enabling regulatory environment for interconnectivity between operators (local and international). Second, governments and regulators need to offer incentives to encourage investment in establishing IXP (such as tax incentives on equipment for IXPs or operator network equipment). Third, in the light of the key findings of this paper on the important role of IXPs in improving fixed-broadband speed and latency, all stakeholders in the process need to cooperate and share information and best practices. National and international organizations, such as Internet Society and the Asia Pacific Network Information Centre, provide expert advice and capacity training in this area.

In Asia and the Pacific, governments recognize the important role of regional cooperation in promoting broadband connectivity through the Asia-Pacific Information Superhighway initiative.[28] The Asia-Pacific Information Superhighway initiative is an intergovernmental platform that facilitates a policy dialogue for stakeholders (governments, private sectors, donors, international organizations, non-governmental organizations, civil society and academia, among others) to discuss challenges related to cross-border connectivity. In particular, to identify tangible solutions for regional cooperation. The Asia-Pacific Information Superhighway initiative focuses on four pillars: infrastructure connectivity (promoting investment in infrastructure connectivity); efficient Internet traffic and network management (including the establishment of IXPs, among others); e-resilience (resilient ICT infrastructure from natural disasters); and affordable broadband access for all. As a result, promoting national and subregional IXPs under the Asia-Pacific Information Superhighway initiative framework would improve Internet speed and latency in countries with special needs (least developed countries, landlocked developing countries and small island developing States).

---

[27] In particular, in markets with a dominant ISP (for example, 60 per cent of market share), smaller ISPs may be required to pay for local connectivity. As a result, setting up a local IXP in that context could be challenging. A potential solution would be for smaller ISPs in a country to connect to a neutral IXP, which would increase market share and leverage for negotiating traffic flow with other dominant ISPs.

[28] For further details, visit www.unescap.org/our-work/ict-disaster-risk-reduction/asia-pacific-information-superhighway.

REFERENCES

Ahmad, Mohammad, and Ratan Guha (2012). Studying the effects of Internet exchange points on Internet topology. *Journal of Information Technology & Software Engineering,* vol. 2, No. 5, pp. 1-12.

Baltagi, Badi (2005). *Econometric Analysis of Panel Data,* 3rd ed. West Sussex, United Kingdom: John Wiley and Sons.

Economist Intelligence Unit (2020). The Inclusive Internet Index 2019. Available at https://theinclusiveinternet.eiu.com/.

_________ (2021). *The Inclusive Internet Index 2019, Methodology Report.* Available at https://theinclusiveinternet.eiu.com/assets/external/downloads/3i-methodology.pdf.

Galperin, Hernán (2013). Connectivity in Latin America and the Caribbean: the role of Internet exchange points. Documento de Trabajo 2013, Number 14. Universidad de San Andres. Available at http://repositorio.udesa.edu.ar/jspui/bitstream/10908/15563/1/%5BP%5D%5BW%5D%20DT14-Galperin%20%28eng%29.pdf.

Grace, Jeremy, and others (2004). Information and communication technologies and broad-based development – a partial review of the evidence. World Bank Working Paper, No. 12. Washington, D.C.: The International Bank for Reconstruction and Development and World Bank.

Internet Society (2014). *The Internet Exchange Point Toolkit & Best Practices Guide.* Available at www.ixptoolkit.org/wp-content/uploads/2016/08/Global-IXPToolkit_Collaborative-Draft_Feb-24.pdf.

_________ (2015). Internet exchange points, an internet society public policy briefing. Available at www.internetsociety.org/wp-content/uploads/2015/10/ISOC-PolicyBrief-IXPs-20151030_nb.pdf.

International Telecommunication Union (ITU) (2012). *Impact of Broadband on the Economy. Broadband Series.* Available at www.itu.int/ITU-D/treg/broadband/ITU-BB-Reports_Impact-of-Broadband-on-the-Economy.pdf.

_________ (2013a). Study on international internet connectivity: focus on Internet connectivity in Latin America and the Caribbean. Available at www.itu.int/en/ITU-D/Regulatory-Market/Documents/International%20Internet%20Connectivity%20in%20Latin%20America%20and%20the%20Caribbean.pdf.

_________ (2013b). Study on international Internet connectivity in sub-Saharan Africa. Available at www.itu.int/en/ITU-D/Regulatory-Market/Documents/IIC_Africa_Final-en.pdf.

Lubis, Nurchaliza, and Helda Febrianty (2018). Internet influencing economic growth: what and how much? A case study of Indonesia using time series data (2001–2016). 3rd International Conference of Integrated Intellectual Community (ICONIC). Available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3216419.

Minges, Michael (2015). Exploring the relationship between broadband and economic growth. Background paper prepared for the World Development Report 2016: Digital Divide. Washington, D.C.: World Bank.

Nunnally, Jum, and Ira Bernstein (1967). *Psychometric Theory*. New York: McGraw-Hill.

Qiang, Christine Zhen-Wei, Alexander Pitt, and Seth Ayers (2004). *Contribution of Information and Communication Technologies to Growth.* World Bank Working Paper, No. 24. Washington, D. C.: International Bank for Reconstruction and Development/World Bank.

TeleGeography (2020). Internet Exchange Map. Available at www.internetexchangemap.com/.

United Nations, Economic and Social Commission for Asia and the Pacific (ESCAP) (2016). State of ICT in Asia and the Pacific 2016: uncovering the widening broadband divide. Working paper by the Information Communications and Technology Disaster Risk Division. Available at www.unescap.org/resources/state-ict-asia-and-pacific-2016-uncovering-widening-broadband-divide.

_________ (2017). *Artificial Intelligence and Broadband Divide: State of ICT Connectivity in Asia and the Pacific 2017.* Available at www.unescap.org/resources/artificial-intelligence-and-broadband-divide-state-ict-connectivity-asia-and-pacific-2017.

United Nations, Economic and Social Commission for Asia and the Pacific (ESCAP), and National Information Society Agency (2016). A pre-feasibility study on the Asia-Pacific Information Superhighway in the ASEAN Sub-region: international traffic and quality analysis, network topography design and implementation model. Technical Report (draft). Available at www.unescap.org/resources/pre-feasibility-study-asia-pacific-information-superhighway-asean-sub-region.

Zaki, Yasir, and others (2014). Dissecting web latency in Ghana. Conference Paper, IMC 2014. Vancouver, Canada, 5–7 November. Available at https://conferences2.sigcomm.org/imc/2014/papers/p241.pdf.

ANNEX

Figure A.1. Internet exchange points by economy, 2019

Source: Economist Intelligence Unit, Inclusive Internet Index 2020 database. Available at https://theinclusiveinternet.eiu.com/ (accessed on 27 February 2020).

Note: IXPs: Internet exchange points.

Table A.1. Internet Inclusive Index 2020 – variables

1.	**AVAILABILITY**
1.1.	**USAGE**
1.1.1.	Internet users; % of households
1.1.2.	Fixed-line broadband subscribers; Per 100 inhabitants
1.1.3.	Mobile subscribers; Per 100 inhabitants
1.1.4.	Gender gap in internet access; % difference
1.1.5.	Gender gap in mobile phone access; % difference
1.2.	**QUALITY**
1.2.1.	Average fixed broadband upload speed; Kbps
1.2.2.	Average fixed broadband download speed; Kbps
1.2.3.	Average fixed broadband latency; ms
1.2.4.	Average mobile upload speed; Kbps
1.2.5.	Average mobile download speed; Kbps
1.2.6.	Average mobile latency; ms
1.2.7.	Bandwidth capacity; Bit/s per Internet user
1.3.	**INFRASTRUCTURE**
1.3.1.	Network coverage (min. 2G); % of population
1.3.2.	Network coverage (min. 3G); % of population
1.3.3.	Network coverage (min. 4G); % of population
1.3.4.	Government initiatives to make Wi-Fi available; Qualitative rating 0-2, 2 = best
1.3.5.	Private sector initiatives to make Wi-Fi available; Qualitative rating 0-2, 2 = best
1.3.6.	Internet exchange points; Number of IXPs per 10 million inhabitants
1.4.	**ELECTRICITY**
1.4.1.	Urban electricity access; % of population
1.4.2.	Rural electricity access; % of population
2.	**AFFORDABILITY**
2.1.	**PRICE**
2.1.1.	Smartphone cost (handset); Score of 0-100, 100 = most affordable
2.1.2.	Mobile phone cost (prepaid tariff); % of monthly GNI per capita
2.1.3.	Mobile phone cost (postpaid tariff); % of monthly GNI per capita
2.1.4.	Fixed-line monthly broadband cost; % of monthly GNI per capita
2.2.	**COMPETITIVE ENVIRONMENT**
2.2.1.	Average revenue per user (ARPU, annualized); US$
2.2.2.	Wireless operators' market share; HHI score (0-10,000)
2.2.3.	Broadband operators' market share; HHI score (0-10,000)

Table A.1. *(continued)*

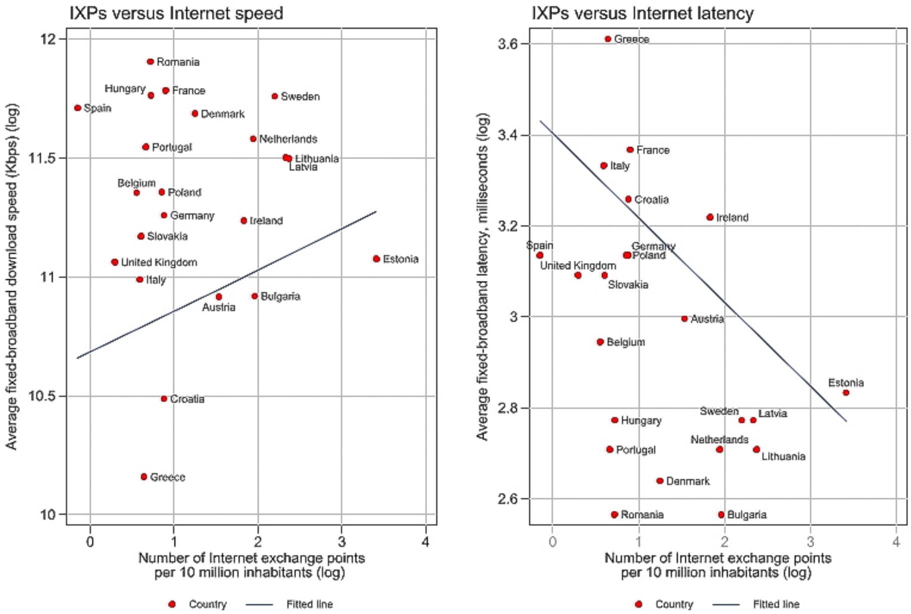
3.	**RELEVANCE**
3.1.	**LOCAL CONTENT**
3.1.1.	Availability of basic information in the local language; Qualitative rating 0-2, 2 = best
3.1.2.	Concentration of websites using country-level domains; Qualitative rating 0-3, 3 = best
3.1.3.	Availability of e-Government services in the local language; Qualitative rating 0-2, 2 = best
3.2.	**RELEVANT CONTENT**
3.2.1.	e-Finance content; Qualitative rating 0-2, 2 = best
3.2.2.	Value of e-finance; %
3.2.3.	e-Health content; Qualitative rating 0-3, 3 = best
3.2.4.	Value of e-health; %
3.2.5.	e-Entertainment usage; %
3.2.6.	e-Commerce content; Score of 0-100, 100 = best
3.2.7.	Value of e-Commerce; %
4.	**READINESS**
4.1.	**LITERACY**
4.1.1.	Level of literacy; % of population
4.1.2.	Educational attainment; Years of schooling
4.1.3.	Support for digital literacy; Qualitative rating 0-3, 3 = best
4.1.4.	Level of web accessibility; Qualitative rating 0-4, 4 = best
4.2.	**TRUST & SAFETY**
4.2.1.	Privacy regulations; Qualitative rating 0-2, 2 = best
4.2.2.	Trust in online privacy; %
4.2.3.	Trust in government websites and apps; %
4.2.4.	Trust in non-government websites and apps; %
4.2.5.	Trust in information from social media; %
4.2.6.	e-Commerce safety; %
4.3.	**POLICY**
4.3.1.	National female e-inclusion policies; Qualitative rating 0-4, 4 = best
4.3.1.1.	Comprehensive female e-inclusion plan; Qualitative rating 0-2, 2 = best
4.3.1.2.	Female digital skills training plan; Qualitative rating 0-1, 1 = best
4.3.1.3.	Female STEM education plan; Qualitative rating 0-1, 1 = best
4.3.2.	Government e-inclusion strategy; Qualitative rating 0-2, 2 = best
4.3.3.	Broadband strategy; Qualitative rating 0-2, 2 = best

Table A.1. *(continued)*

4.3.4.	Funding for broadband buildout; Qualitative rating 0-1, 1 = best
4.3.5.	Spectrum policy approach; Qualitative rating 0-2, 2 = best
4.3.5.1.	Technology-neutrality policy for spectrum use; Qualitative rating 0-1, 1 = best
4.3.5.2.	Unlicensed spectrum policy; Qualitative rating 0-1, 1 = best
4.3.6.	National digital identification system; Qualitative rating 0-2, 2 = best
BACKGROUND VARIABLES	
BG1.	Nominal GDP; US$ billions
BG2.	Population; Millions
BG3.	Urbanization rate; % of population
BG4.	GNI per capita; US$ per person
BG5.	GINI coefficient; Score, 0-100; 0 is perfect equality; 100 is perfect inequality
BG6.	Population under the poverty line; % of population
BG7.	Total electricity access; % of population
BG8.	Cable landing stations; Number of cable landing stations per 10 million inhabitants
BG9.	Percentage of schools with Internet access; % of schools
BG10.	Global Peace Index; Score, 1-5; 1 = best
BG11.	Democracy Index; Score, 0-10; 10 = best
BG12.	Corruption Perceptions Index; Score, 0-100; 100 = best
BG13.	EIU Business Environment Rankings; Score, 1-10, 10 = high
BG14.	UN E-Government Development Index; Score, 0-1; 1 = best
BG15.	Internet users (population); Millions
BG16.	Offline population; Millions
BG17.	Plan addressing female-driven innovation and women-owned businesses; Qualitative rating 0-1, 1 = best
BG18.	Internet access gender gap; Difference in percentage points
BG19.	Mobile phone access gender gap; Difference in percentage points
BG20.	Internet users (percent of population); % of population
BG21.	Male Internet users; % of male population
BG22.	Female Internet users; % of female population
BG23.	Male mobile phone subscribers; % of male population
BG24.	Female mobile phone subscribers; % of female population
BG25.	Total fixed line broadband subscribers; Number of subscriptions

Source: Economist Intelligence Unit, Inclusive Internet Index 2020 database. Available at https://theinclusiveinternet.eiu.com/ (accessed on 27 February 2020).

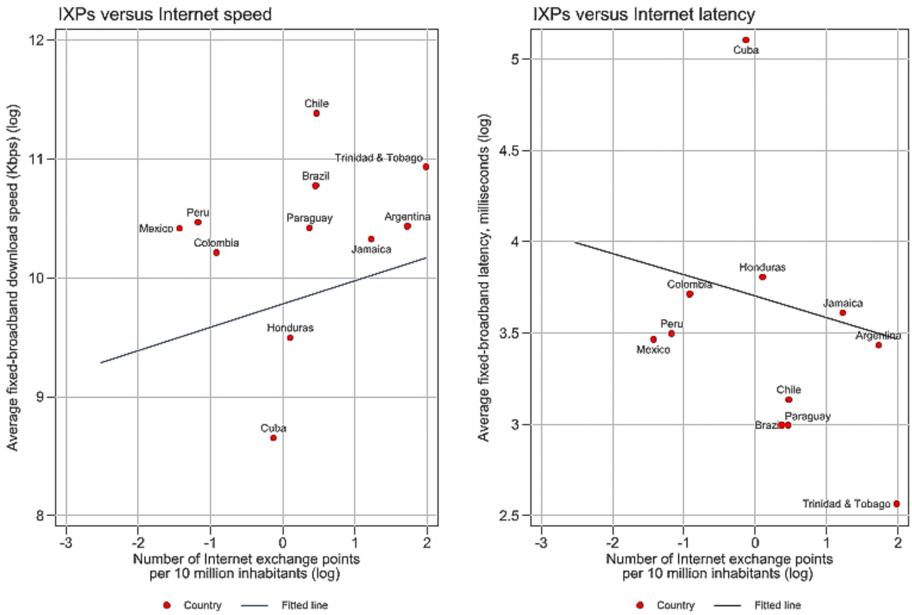
Figure A.2. Internet exchange points versus fixed-broadband speed and latency, Europe 2019



Source: Economist Intelligence Unit, Inclusive Internet Index 2020 database. Available at https://theinclusiveinternet.eiu.com/ (accessed on 27 February 2020).

Note: IXPs: Internet exchange points.

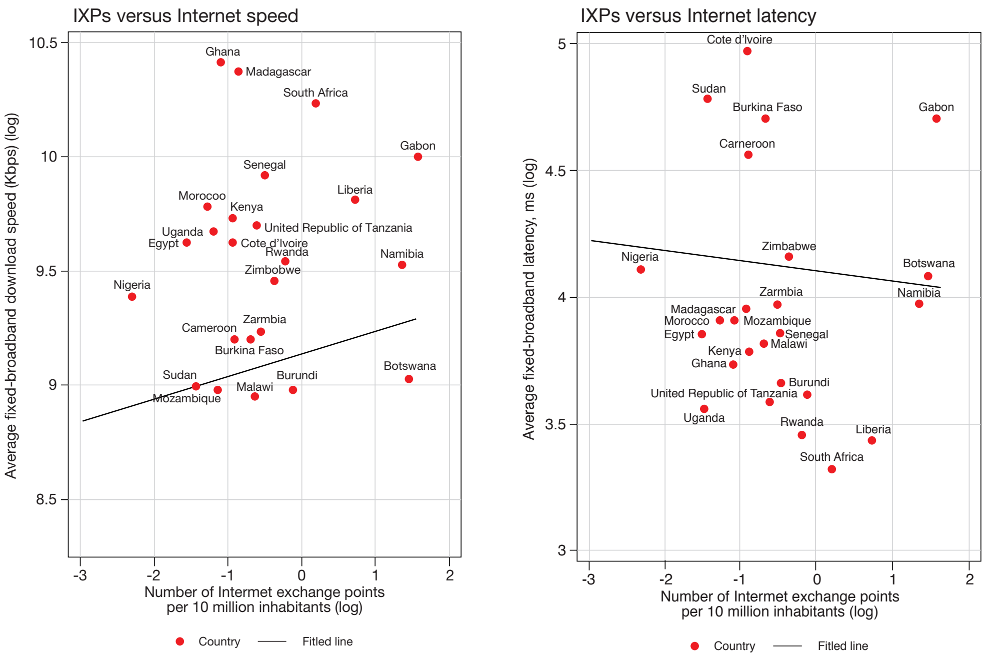
Figure A.3. Internet exchange points versus fixed-broadband speed and latency, Latin America and the Caribbean 2019



Source: Economist Intelligence Unit, Inclusive Internet Index 2020 database. Available at https://theinclusiveinternet.eiu.com/ (accessed on 27 February 2020).

Note: IXPs: Internet exchange points.

Figure A.4. Internet exchange points versus fixed-broadband speed and latency, Africa 2019



Source: Economist Intelligence Unit, Inclusive Internet Index 2020 database. Available at https://theinclusiveinternet.eiu.com/ (accessed on 27 February 2020).

Note: IXPs: Internet exchange points.