Estimating the effects of Internet Exchange Points on Fixed-broadband speed and latency

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1. Executive Summary

Access to the Internet contributes to socio-economic development. However, access to affordable and reliable broadband connectivity is not universal, particularly in countries with special needs (Least Developed Countries (LDCs), Land-locked Developing Countries (LLDCs) and Small Island Developing States (SIDS)). According to the latest ICT statistics from the Economist Intelligence Unit's 'Inclusive Internet Index 2020'[1], the average fixed-broadband access, speed, latency, and affordability, are well-developed in high-income countries, but significantly lacking behind in low-income countries.

Internet exchange points (IXPs) are physical (switch or server) locations where different networks connect to exchange Internet traffic. IXPs are vital for improving the affordability and quality of broadband connectivity, within and between countries, by keeping Internet traffic 'local' within the network of connected networks, thereby keeping costs and latency low.

This Working Paper estimates the relationship between the number of IXPs and fixed-broadband speed and latency in 74 countries from 2016 to 2019, using a balanced panel dataset developed by the Economist Intelligence Unit for its 'Inclusive Internet Index'. While several studies have established a positive role of IXPs on Internet speed and latency, majority of the earlier studies are technical studies examining the traffic routes in specific networks. This Working Paper therefore contributes to this literature by triangulating earlier findings using an econometric model. The recent availability of the panel dataset on IXPs, speed and latency by the Economist's 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% increase in the number of IXPs per 10 million inhabitants, the speed of fixed-broadband download speed (Kbps) is expected to increase by about 0.8%. The preliminary findings further highlighted that the presence of IXPs are driven by income with higher number of IXPs in high-income countries and vice versa. In addition, the preliminary findings highlighted a statistically significant and negative relationship between the number of IXPs and fixed-broadband latency. For every 1% increase in the number of IXPs per 10 million inhabitants, the latency (delay in milliseconds) of fixed broadband is expected to decrease by about 0.4%.

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); neutral location and management of IXP as a platform for all operators to connect; conducive regulatory environment that supports an open market for telecommunication services. As a

[1] Economist Intelligence Unit, Internet Inclusive Index 2020, 2020, available from: https://theinclusiveinternet.eiu.com/ (accessed on 27 February 2020)

result, these challenges pose important policy implications for policymakers on ensuring the sustainability of IXPs.

2. Background

Access to the Internet contributes to socio-economic development (see Grace et al. 2004; Qiang, Pitt & Ayers 2004; ITU 2012; Minges, 2016; Lubis & 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 (LDCs), Land-locked Developing Countries (LLDCs) and Small Island Developing States (SIDS)).

According to the latest ICT statistics from the Economist Intelligence Unit's 'Inclusive Internet Index 2020'[2] on fixed-broadband access, speed (Kbps), latency[3] (ms), and affordability[4], the average access to fixed and mobile broadband subscriptions are highest in high-income countries (33% and 121% respectively), compared to low-income countries (2% and 88%). ESCAP studies (2016b & 2017) have highlighted the widening digital divide, not only by income but by geographic regions as well. The average monthly fixed-broadband upload (36,127 Kbps) and download (64,112 Kbps) speeds are highest in high-income countries, compared to lower Internet speeds in low-income countries (13,005 Kbps and 14,521Kbps 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%)[5] and mobile-broadband services (0.7%) are affordable in high-income countries, compared to low-income countries (13% and 2% respectively). An ESCAP study (2016a) measured the Internet speed and traffic in CLMV (Cambodia, the Lao People's Democratic Republic, Myanmar, and Viet Nam) countries highlighted that most of the international traffic of these countries have been exchanged outside the region (in North America or Europe).

A national Internet exchange point (IXP) facilitates access of all users to online services[6] and improve the affordability and quality of Internet services. An IXP is a physical location where different Internet provider networks connect to exchange traffic with each other using a copper

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[2] Economist Intelligence Unit, Internet Inclusive Index 2020, (2020), available from: https://theinclusiveinternet.eiu.com/ (accessed on 27 February 2020)
[3] Delay it takes to send information from one point to another in milliseconds (ms)
[4] Monthly expenditure on broadband services as percentage of gross national income per capita
[5] According to the United Nations Broadband Commission, a target of broadband services should be made affordable in developing countries at less than 2% of monthly Gross National Income per capita by 2025. For further details, refer to: https://www.broadbandcommission.org/Pages/targets/Target-2.aspx
[6] Acknowledging the comment from Mr. Kisione Finau that there are some online services that does not require IXPs especially if such online service is configured to be used within an organization's Internet ecosystem. For example, the University of the South Pacific (USP) uses an online service called BANNER (ERP) to route all USP Internet traffics local between campuses/countries without the need to go through an IXP.

or fibre-optic cable through one or more Ethernet switches or ,server (Internet Society, 2014). 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 information 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.

As a result, a national IXP significantly improves the efficiency of Internet traffic resulting in cost savings. This is made possible by eliminating the routing of Internet traffics through expensive long-distance traffic routes outside the country before returning back to the country. Also, consolidating of national traffic from different networks significantly improves national Internet traffic network management and eliminating the need for multiple physical links between local network operators and international operators. In addition, download speeds for websites improve significantly thereby encouraging the development of new local content and services as well as opportunities for productive use of Internet for other purposes (for example, e-commerce or e-government services).[7]

Past research literatures (mostly from the technology side) have pointed to positive effects of IXPs on improving Internet speed and latency. Ahmad and Guha (2010) tested the latency of Internet traffic going through IXPs and found that traffic going through IXPs encountered lesser delays than normal links, even though the presence of IXPs did not decrease the length of an Internet network path. Galperin (2013) analyzed the IXPs in Latin America and the Caribbean and concluded that IXPs in this region reduced access costs, increased Internet quality, promoted 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 IXP as a national asset with clear benefits to a country's Internet network architecture (ITU 2013a & ITU 2013b).

An Internet Society study (2015) best captures the benefits of IXPs as follows:

a) lowering 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) ensuring 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 an ISP's overall Internet traffic;
c) creating 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;

[7] For a discussion on the benefits of IXPs, refer to Internet Society, 'The Internet Exchange Point Toolkit & Best Practices Guide', 2014, available from: https://www.ixptoolkit.org/wp-content/uploads/2016/08/Global-IXPToolkit_Collaborative-Draft_Feb-24.pdf

d) attracting 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) contributing to the development of the local Internet ecosystem and local service hosting/local content development. IXP creates a local environment that attracts a variety of other services, including domain name servers and content and web caches;
f) improving local users' quality of access by providing more-direct network connections for local content producers and consumers;
g) improving the level of stability and continuity of access (i.e. IXP switching capability provides 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); and
h) IXPs 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).

An ESCAP study (2016a) highlighted that IXP should be designed in order to identify the best way to connecting traffic routes to each destination. In particular, IXPs should be neutral and open to any operator. Also, the study recommended the need for all stakeholders involved to agree on common principle on the traffic management. The common principle may include: the requirement for exchanging of routing information with all Internet Service Providers connected to the IXP; and the need for establishing a neutral organization capable of operating and managing IXP.

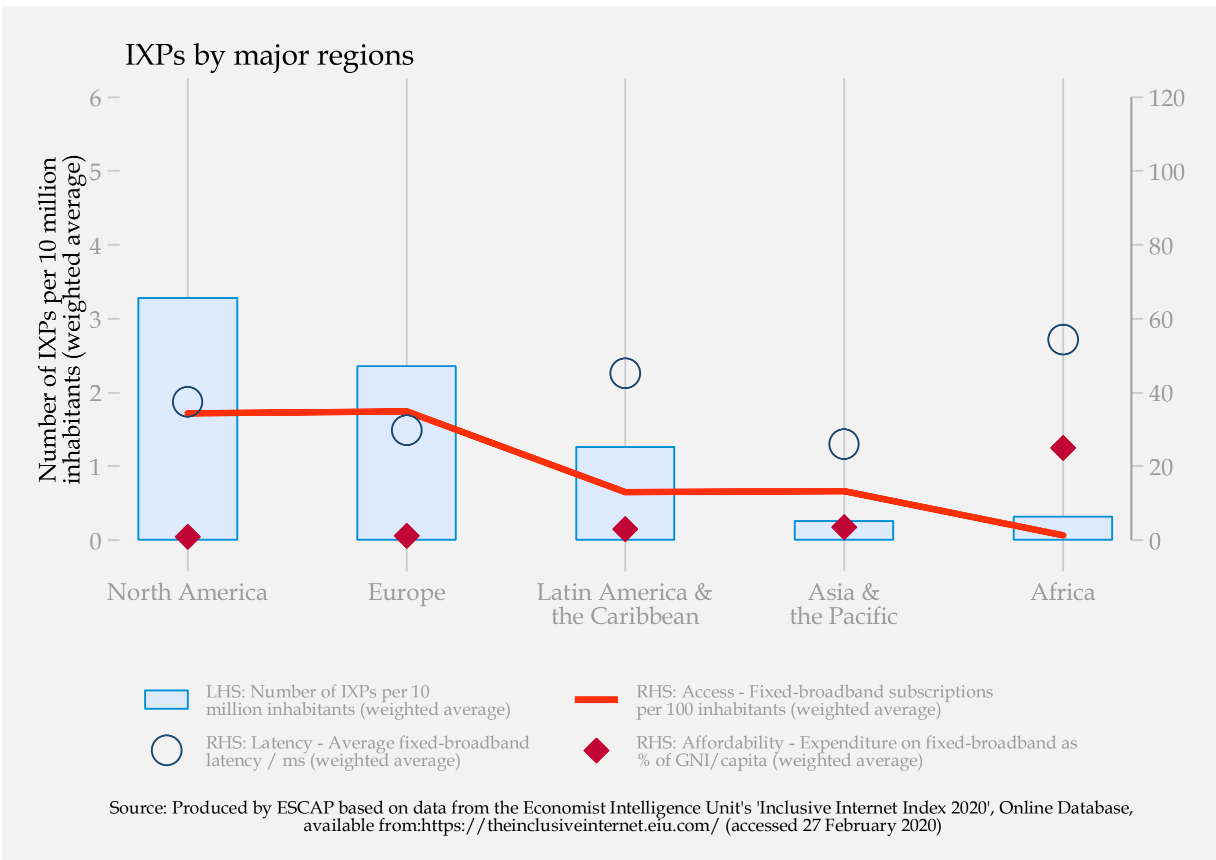
While recognizing the technical benefits of IXPs, establishing an IXP (especially when it involves operators from several countries to connect) is not clear cut. Many IXPs are established for public service (non-commercial) requiring the collaboration of all ISPs in a country. However, its subsequent 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 to each other. Hence, a great deal of time and resources are required to consolidate and build trust between 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 include the difficulty of establishing a neutral (physical location and operation of an IXP should be neutral and agreed upon by all IXP parties), when one operator or government authority opted to host IXP, thereby undermining the neutrality and independence of an IXP.

3. IXP trends

National IXPs have been deployed in many countries across the world. Comparing between different major regions of the world, North America (driven by the United States), and Europe are the two major regions with the highest number of IXPs per 10 million inhabitants.[8] This is followed by Latin America and the Caribbean, Asia and the Pacific, and Africa (see Figure 1). The development of IXPs are also prevalent in high-income countries, compared to low-income countries (see Figure 2). As a result, the development of IXPs (per 10 million inhabitants)[9] are severely lacking in low-income countries of Africa and Asia and the Pacific.

Figure 1: IXPs by major regions

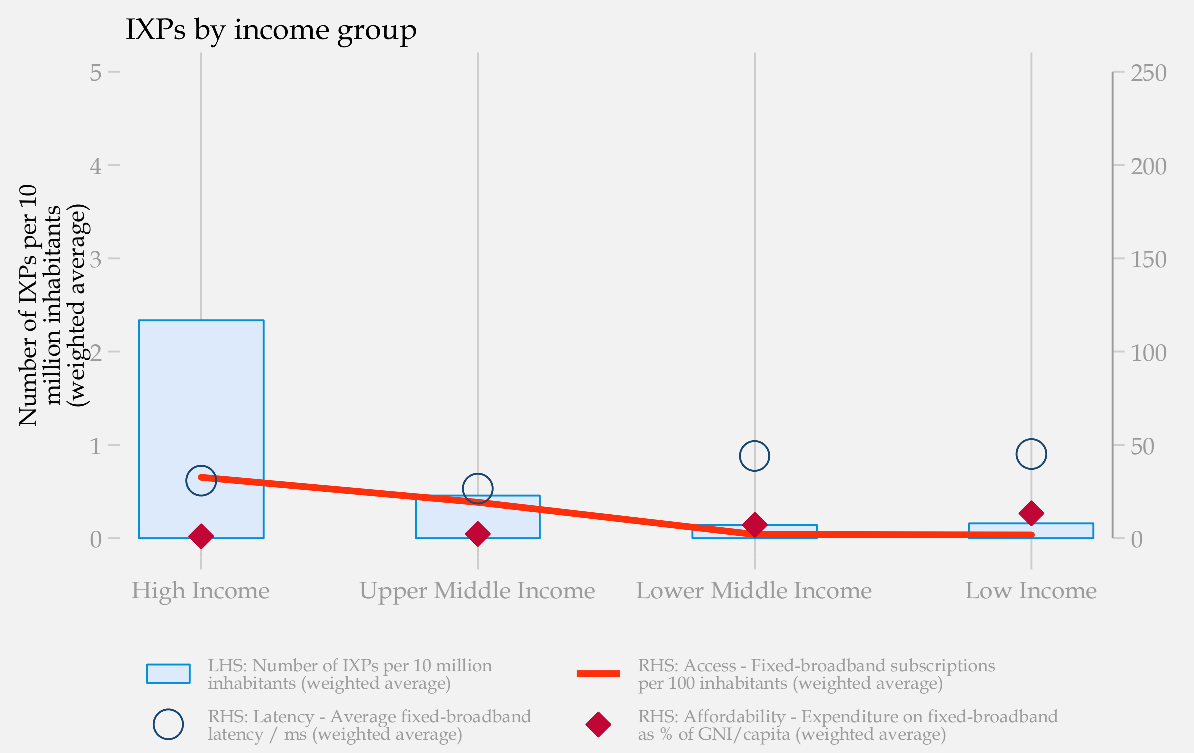


[8] Variable reported by the Inclusive Internet Index database (https://theinclusiveinternet.eiu.com/) of the Economist Intelligence Unit, for better reflection of the level of IXPs within countries/regions. Further discussion on this variable in the next section.

[9] 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 higher the population (or population rate in 10 million inhabitants) of a country is, 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.

For a better understanding on the role of IXPs on efficient fixed-broadband speed and latency in countries across the world, IXP developments can be assessed against broadband efficiency indicators, namely fixed-broadbands' access, 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, 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) also experienced the highest access to fixed-broadband subscription. On the other hand, low-income countries with the lowest access to fixed-broadband subscription also experienced the lowest number of IXPs.

Figure 2: IXPs by income group



Source: Produced by ESCAP based on data from the Economist Intelligence Unit's 'Inclusive Internet Index 2020', Online Database, available from:https://theinclusiveinternet.eiu.com/ (accessed 27 February 2019)

Affordability (monthly expenditure on fixed broadband as a percentage of gross national income per capita)[10] of fixed-broadband subscription is lowest (very affordable) in high-income countries, compared to low-income countries (Figure 2). Majority of these low-income countries are

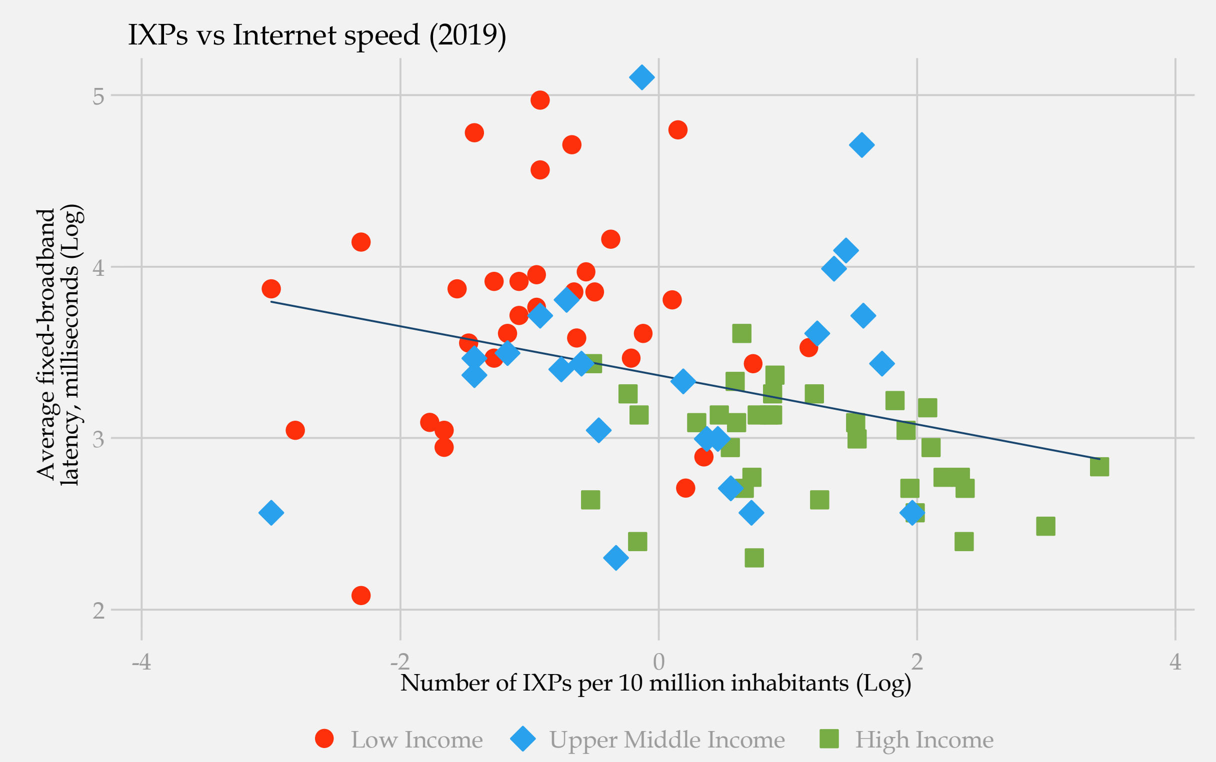
[10] The United Nations Broadband Commission considers a target of less than 2% as affordable.

geographically found in Africa, and Asia and the Pacific (Figure 2), compared to more affordable fixed-broadband subscriptions in North America and Europe.

At the country level, the number of IXPs per 10 million inhabitants varies significantly between countries (see Annex 1, Figure 6). The top 10 countries with the highest number of IXPs per 10 million inhabitants include: Estonia, Bahrain, Lithuania, Singapore, Latvia, Sweden, New Zealand, Australia, Trinidad & Tobago, and Bulgaria. Majority (4 countries) are from Europe followed by Asia and the Pacific region (3 countries). On the other hand, the 10 countries with the lowest IXPs per 10 million inhabitants include: Algeria, Azerbaijan, El Salvador, Ethiopia, Guatemala, Nicaragua, Oman, Venezuela, Qatar and China. Majority of these countries (4) are in South America, followed by Africa (2) and Asia (2). The IXP variable is therefore a useful indicator in 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 compared to low-income countries (see Figure 2 & Figure 3). High-income countries have invested more on modern ICT infrastructure connectivity resulting in faster fixed-broadband speeds.

Figure 3: Fixed-broadband Speed (Kbps)



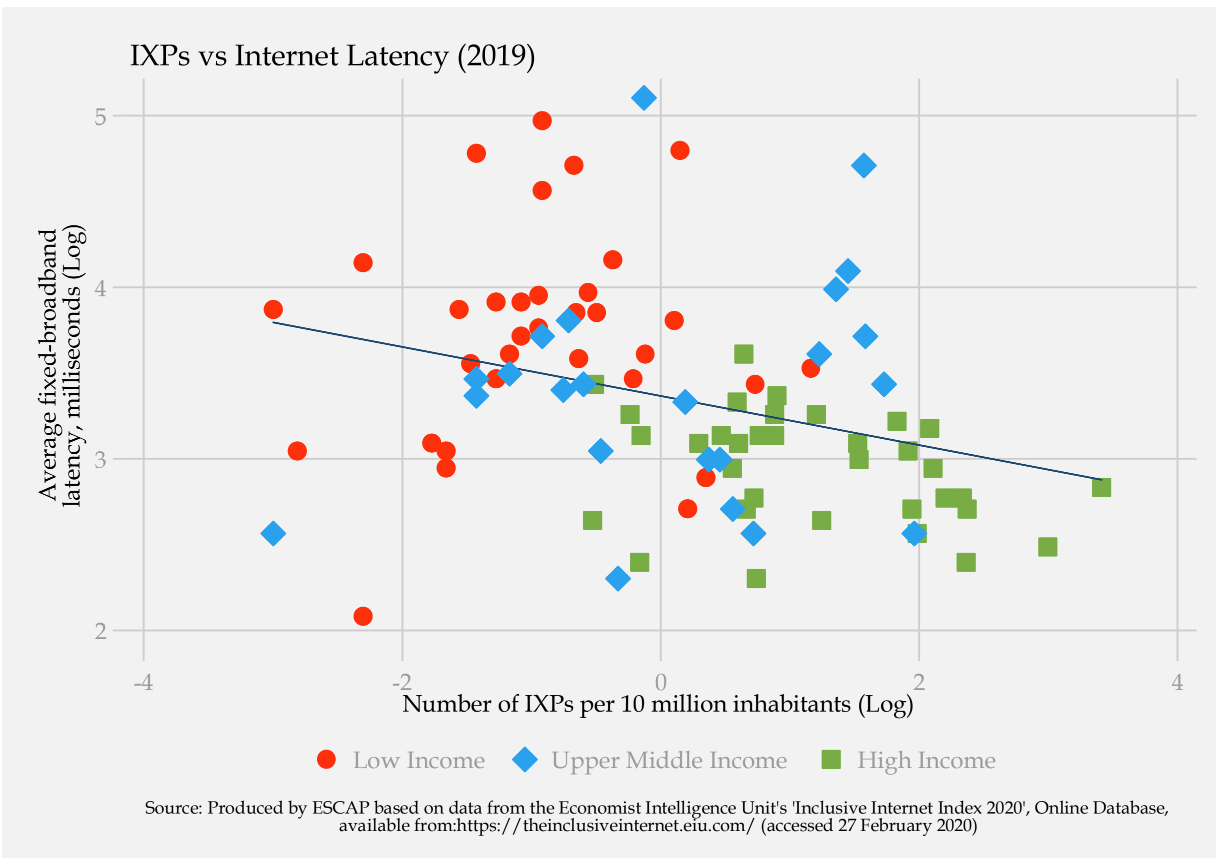
Source: Produced by ESCAP based on data from the Economist Intelligence Unit's 'Inclusive Internet Index 2020', Online Database, available from:https://theinclusiveinternet.eiu.com/ (accessed 27 February 2020)

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.

Latency (ms) trend shows a reverse relationship with the IXP trend. This is, high-income countries have the lowest Internet latency compared to the low-income countries with the highest Internet latency (Figure 2 & Figure 4). Similarly, Africa with the lowest number of IXPs experienced the highest Internet latency compared to North America and Europe.

Fixed-broadband latency (ms) also have similar trends with shorter delays experienced in networks of high-income countries compared to longer delays in low-income countries in 2020 (Figure 4). Fixed-broadband latency (ms) is a complex challenge with multi-dimension causes. Zaki et al. (2014) highlighted that slow Internet in Developing countries are due to geographic locations (further distances create higher latency); infrastructure challenge (low bandwidth links and high network contents); and routing problems (inefficient protocols and architectural issues such as content distribution networks (CDN) server placement).

Figure 4: Fixed-broadband Latency(ms)



According to the Inclusive Internet Index 2020 statistics, the average latency (ms) on fixed-broadband subscriptions is highest in Africa (56 ms), followed by Latin America & Caribbean (38 ms), North America (25ms), Europe (22 ms) and Asia and the Pacific (21 ms). In the case of mobile-broadband subscriptions, latency is shortest in Europe (39 ms), North America (49), Asia and the Pacific (48 ms), Latin America & 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 are prominent in higher income countries and vice versa. In addition, countries with higher number of IXPs per 10 million inhabitants also tend to have higher access to broadband subscriptions, less broadband latency, and more affordable. These trends raise important policy questions about the role of IXPs on fixed-broadband efficiency (in terms of latency and speed), particularly, in countries of which IXPs are predominantly missing (i.e. low-income countries with less access to broadband Internet, higher latency, and unaffordable).

4. Analytical framework

The literatures from technology and communications discussed in earlier section point to a positive relationship between the presence of an IXP on 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 for measuring traffic routes. However, limited attention has been given to statistically evaluating this relationship. This Working Paper attempts to fill that gap by empirically testing the relationship between the number of national IXPs and fixed-broadband speed and latency.

This Working Paper therefore hypothesize that the efficiency (speed and latency) of fixed-broadband traffic flows exchanged between different ISPs within a country improve (i.e. speed increases and latency decreases), as the number of IXPs increases. The hypothesized relationships between the main independent and dependent variables are summarized in Table 1.

Table 1: Main Independent and Dependent variables

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:* (1). Speed (Fixed-broadband download speed – Kbps) (+) (2). Latency (Fixed-broadband latency (average, ms) (-)
Source: Author's consolidation Note: (+) 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:

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

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

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. We would therefore expect that an increase in the number of IXPs may also see 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.

Other control variables include the log-transformed[11] 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 (USD billions) (Gdp) ; market size—population (millions) (Pop). In addition, 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 fixed effects method. Baltagi (2005) best captures the benefits of fixed effects by highlighting that fixed effects method are effective when the question of interest controls for individual heterogeneity (variable that changes over time but not across entities). Baltagi (2005) 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 a not detectable in non-panel structured datasets. However, Baltagi (2005) also highlighted the limitations of the fixed-effects method linked to collection of data for the panel dataset (problems with designing and data collection; missing observation; and data collection high costs).

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

With respect to the appropriateness of the use of fixed-effect method, the Sargan-Hansen statistics[12] rejected the null hypothesis that the errors are correlated with the exogenous variables in the model, and therefore fixed-effect method is the preferred method. Modified Wald test[13] indicated the presence of heteroskedasticity, and therefore Huber/White estimator was used to obtain heteroskedasticity-robust standard errors.

This Working Paper is interested in assessing the relationship between IXPs and fixed-broadband speed and latency in 74 countries between 2016 and 2019. Fixed-effect method is therefore ideal in analyzing the impact of a particular variable that vary over time. In addition, the fixed-effect method controls for any potential correlation within the country and the independent/dependent variables that may render the estimation bias, by removing the effect of those time-invariant biases.[14]

5. Data

The Working Paper uses a balanced short panel of 74 countries from 2016 to 2019. The panel dataset was developed and maintained by the Economist's Intelligence Unit (EIU), for computing the 'Inclusive Internet Index'[15].

The Inclusive Internet Index includes 53 indicators categorized under four key areas of: 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 receive 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[16]. Variables

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

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

[14] For further details, refer to Baltagi BH, Econometric analysis of panel data, 2005, Third edition, John Wiley & Sons Ltd, West Sussex.

[15] https://theinclusiveinternet.eiu.com

[16] The Economist Intelligence Unit, The Inclusive Intern Index 2019 Methodology Report, available from: https://theinclusiveinternet.eiu.com/assets/external/downloads/3i-methodology.pdf (accessed 28 October 2019)

categorized under each key area are listed in Table 3. List of all variables is attached as Table 3 (Annex 2).

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

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

The dataset is extremely useful for this study since 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 online'[17], it does not include statistics on IXPs.

Other credible datasets with ICT indicators, such as the World Bank's 'World Development Indicators'[18] and the World Economic Forum 'Networked Readiness Index'[19], also do not collect statistics on the number of IXPs per population. While a number of online platforms, such as TeleGeography's Internet Exchange Map[20], the Internet Society's IXP platform[21], and ESCAP-ISOC's IXP Mapping Project for Asia-Pacific[22], do provide statistics on the number of IXPs in each country, these online sources do not provide panel data with changes on a yearly basis (i.e. how many IXPs established in each country every year).

In addition, the Inclusive Internet Index dataset also collect statistics on other policy variables that allows for testing of fixed-broadband speed and latency, as well as other interesting policy

[17] https://www.itu.int/en/publications/ITU-D/pages/publications.aspx?parent=D-IND-WTID.OL-2019&media=electronic
[18] https://data.worldbank.org/
[19] http://reports.weforum.org/global-information-technology-report-2016/networked-readiness-index/?doing_wp_cron=1572941503.7552540302276611328125
[20] https://www.internetexchangemap.com/
[21] https://www.internetsociety.org/issues/ixps/
[22] https://www.unescap.org/our-work/ict-disaster-risk-reduction/asia-pacific-information-superhighway/ixpmap

variables for future researches (such as Internet affordability, local content, trust and safety, policies on female e-inclusion, female STEM education, spectrum policy, national digital identification policy among others).

Limitations of the Inclusive Internet Index dataset however are acknowledged. First, since it is a relatively new dataset (2016-2019), it provides limited observations for a stable estimation result. As a result, the results of this Working Paper may need to be re-visited after 3 to 5 years into the future to allow for additional years with observations in the estimation. Nunally (1967) suggested that in multiple regression modeling, for each independent variable (X), there should be at least 10 observations (i.e. 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 Working Paper, there are seven variables (excluding the constant) with observations of around 189 (double the acceptable level).

Second, the 2020 version of the dataset only included 100 countries with several Least Developed Countries (LDCs), Land-locked Developing Countries (LLDCs) and Small Island Developing States (SIDS) noticeably missing.[23] However, the countries that are included do represent well the global trend with top ten biggest economies in the world included: United States, China, Japan, Germany, United Kingdom, India, France, Brazil, Italy and Canada. By population, more than ¾ of the world's population are controlled for with the inclusion of major populous countries such as China, India, United States, Indonesia, Brazil, Pakistan, Nigeria, Bangladesh, Russian Federation, and Mexico. As a result, the overall results of the estimations generated from the Working Paper are indeed representative of the global trend.

6. 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 negatively correlated with fixed-broadband latency for Asia and the Pacific (Figure 5).

Countries such as Singapore and Australia are 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 lowest fixed-broadband latency.

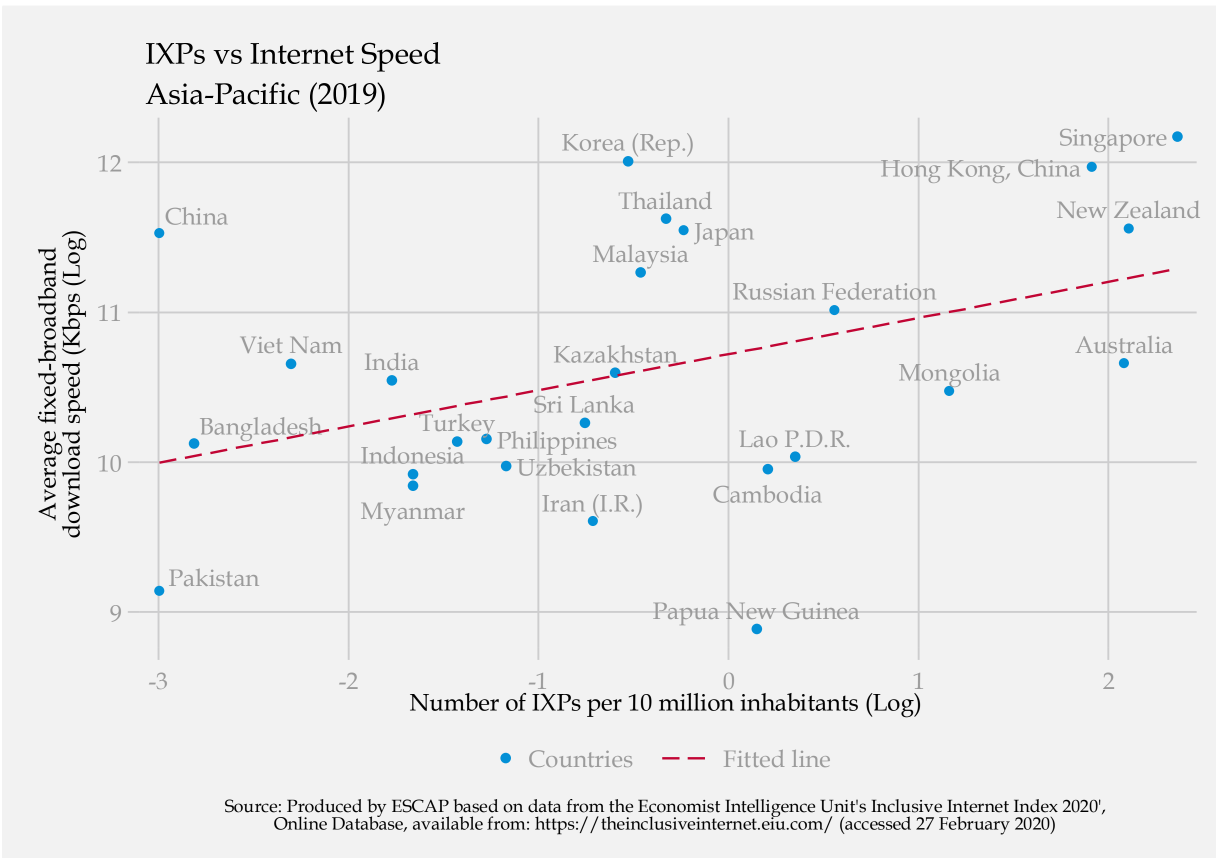
In the case of Europe, a similar IXP correlation pattern is found with respect to fixed-broadband speed and latency (Figure 7). Estonia and Lithuania are the leading countries in Europe for high

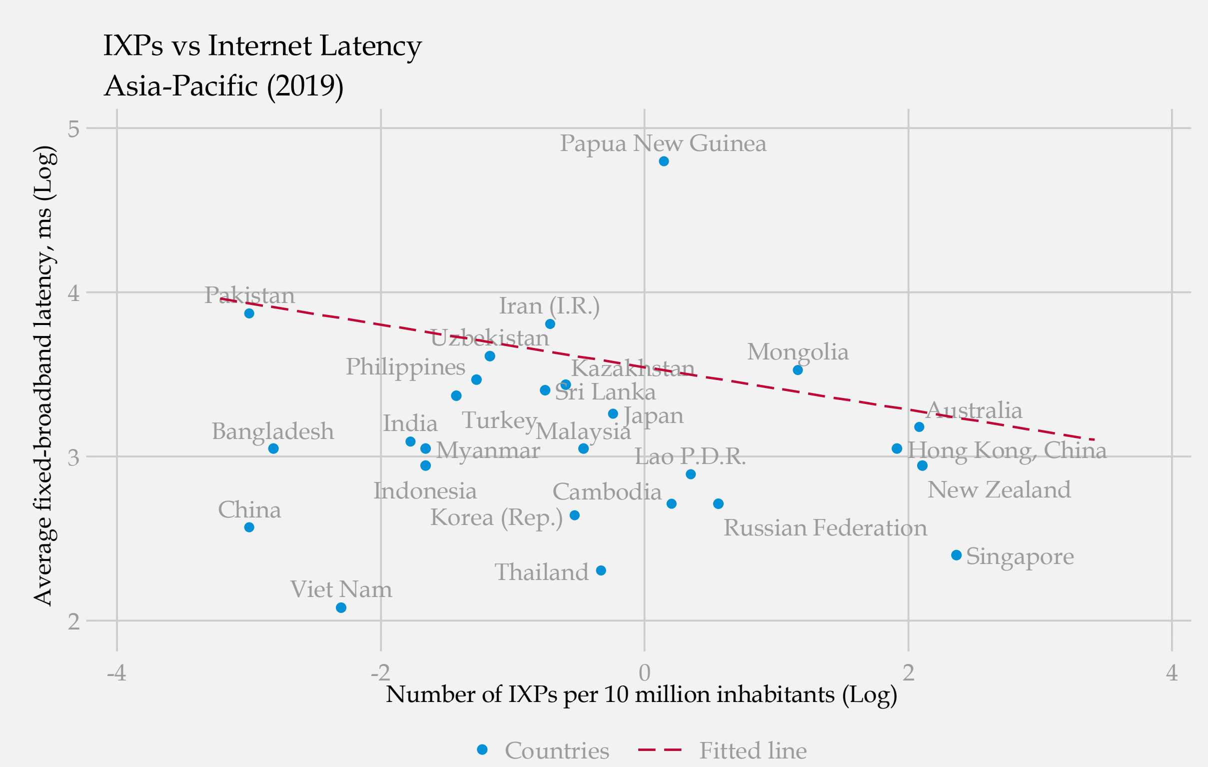
[23] Controlling for smaller countries in the dataset is also a challenge considering that the variable required for computing a new control variable (such as 1 million per inhabitants) for smaller countries is not available from the EIU dataset. This missing variable is the number of IXPs established in each of the years. Thanks to Dr. Kiyoung Ko for raising this issue to my attention.

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 & Tobago are the two leading countries with respects to positive correlation between the number of IXPs and fixed-broadband speed, while negatively correlated with fixed-broadband latency. (Figure 8). Similar pattern is also found for Africa (Figure 9).

Figure 5: IXPs vs Fixed-broadband Speed and Latency





Source: Produced by ESCAP based on data from the Economist Intelligence Unit's Inclusive Internet Index 2020', Online Database, available from: https://theinclusiveinternet.eiu.com/ (accessed 27 February 2020)

The relationship between the number of IXPs and fixed-broadband speed and latency was further assessed through an econometric model which controls for the effects of other variables. The results of the fixed-effects method are presented in Table 5.

The result of the fixed-effects estimation indicates 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% increase in the number of IXPs per 10 inhabitants, the speed of fixed-broadband download speed (Kbps) is expected to increase by about 0.8%[24].

[24] Or for every 10% increase in the number of IXPs per 10 inhabitants, the speed of Fixed download speed (Kbps) increases by about $(1.10^{0.8} - 1) * 100$ =8%

Table 5: Fixed-effects estimation results

	Dep. Var 1 **Fixed-broadband download speed - Kbps (Log)**	*Dep. Var 2* **Fixed-broadband latency (avg, ms) (Log)**
Independent Variables		
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

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

In addition, the results indicate that the number of IXPs per 10 million inhabitants is statistically significant and negatively corelated with fixed-broadband latency (ms) (Dep. Var 2). For every 1% increase in the number of IXPs per 10 inhabitants, fixed-broadband latency (ms) is expected to decrease by about 0.4%. Overall, the preliminary results from the fixed-effects estimation provides empirical evidence to support the important role of IXPs on improving efficient fixed-broadband speed and latency among 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 regards to the access of subscribers to fixed-broadband services ($FixBro$), a positive relationship is found between increases in access to fixed-broadband services and increases in fixed-broadband speed. On the other hand, an increase in access to fixed-broadband services decreases fixed-broadband latency (ms). This finding is aligned with the literature on digital divide of country experiences such as the Republic of Korea, Singapore, Japan and Australia, with very high rate of access to fixed-broadband Internet and also experiencing higher fixed-broadband speed and lowest latency (ms), compared to low-income countries.

Controlling for the level of cross-border connectivity[25] 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 correlated with fixed-broadband latency. The more cable landing stations per population, the better and stable the fixed-broadband connection will be, as 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, a second cable could provide the broadband lifeline to the country. In addition, access to multiple cable stations (multiple cross-border fiber cables) implies that higher chances of connecting to more 'efficient' shorter traffic routes of which can improve fixed-broadband latency.

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 is proxied by the quality[26] 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 (USD billions) (Gdp) is a proxy for income in countries. A positive and statistically significant relationship is found between 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 and 2017). Population (millions) (Pop) was used as a proxy of country/market size and found a positive relationship[27] with fixed-broadband speed, and a negative relationship with fixed-broadband latency. This finding suggests the presence of economies of scale. In particular, as market size increases, demand for Internet services increases which incentivize network operators to invest on improving Internet speed and latency.

[25] Considering that >70% of global Internet traffic are routed through fibre-optic cables.
[26] Qualitative rating (0-1, 1=best)
[27] Statistically significant in both cases.

7. Conclusion and policy implication

The preliminary findings of this Working Paper provide econometric evidence towards the important role of IXPs on 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% increase in the number of IXPs per 10 million inhabitants, the speed of fixed-broadband download (Kbps) is expected to increase by 0.8%. In addition, the presence of IXPs are common in high-income countries and vice versa. Countries with higher number of IXPs also tend to have higher access to broadband Internet[28] and 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); neutral location and management of IXP as a platform for all operators to connect; and conducive regulatory environment that supports an open market for telecommunication services.[29]

As a result, these challenges pose three important policy implications for policymakers on ensuring the sustainability of IXPs. First, strong political support is needed. The government championing the process needs 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 provide incentives for encouraging investment opportunities on establishing IXP (such as tax incentives on equipment for IXPs as well as operator network equipment). Third, in light of the key findings of this Working Paper that provide supports to the important role of IXPs on improving fixed-broadband speed and latency, all stakeholders in the process, need to cooperate and share information and best practices. National and international organisations (such as Internet Society and the Asia Pacific Network Information Centre) provide expert advice and capacity training on this area.

In Asia and the Pacific, governments recognize the important role of regional cooperation on promoting broadband connectivity by endorsing the Asia-Pacific Information Superhighway (AP-IS) initiative[30]. The AP-IS initiative is an intergovernmental platform that facilitates the policy dialogue of various stakeholders (governments, private sectors, donors, international

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

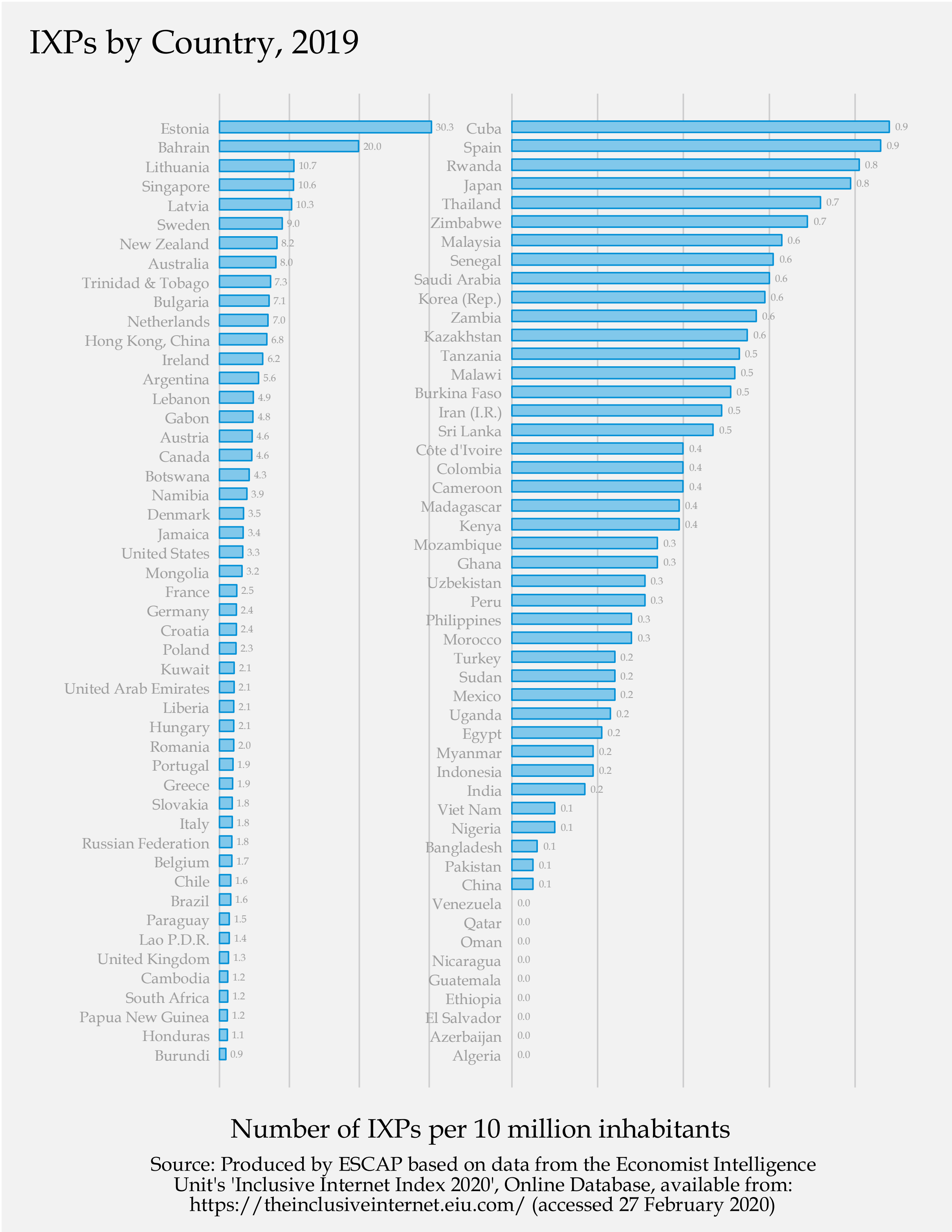
[29] In particular, in markets where a dominant ISP (for example, 60% of market share), they may require smaller ISPs to pay for local connectivity. As a result, setting up a local IXP in that context could be challenging. A potential solution would be for smaller ISPs in a country to connect to a neutral IXPs, which would increase market share and leverage for negotiating traffic flows with other dominant ISPs. Thanking Che-Hoo Cheng for flagging this alternative solution.

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

organisations, non-government organisations, civil society, academia among others), to discuss challenges on cross-border connectivity. In particular, to identify concrete solutions for regional cooperation. The AP-IS initiative focusses on four pillars namely: 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.

8. Annexes

Figure 6: IXPs by Country, 2019



Annex 2:

Table 3: Internet Inclusive Index 2020 - Variables

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); USD
2.2.2) Wireless operators' market share; HHI score (0-10,000)
2.2.3) Broadband operators' market share; HHI score (0-10,000)
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) National broadband strategy; Qualitative rating 0-2, 2=best
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

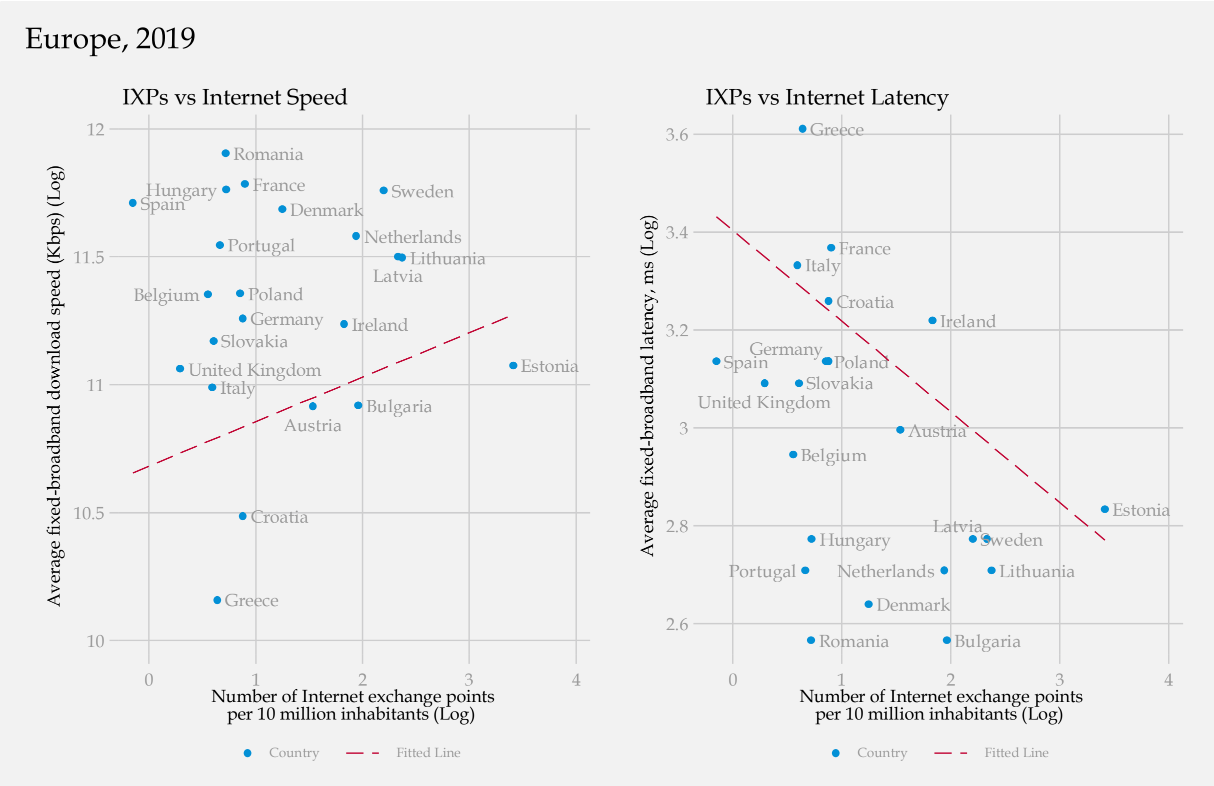
BG1) Nominal GDP; USD billions
BG2) Population; Millions
BG3) Urbanization rate; % of population
BG4) GNI per capita; US$ per person
BG5) GINI coefficient; Score, 0-100; 0 is perfect equality; 100 is perfect inequality
BG6) Population under the poverty line; % of population
BG7) Total electricity access; % 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: The Economist Intelligence Unit, The Inclusive Internet Index 2020, Online Database, available from: https://theinclusiveinternet.eiu.com/ (accessed 27 February 2020)

Annex 3:

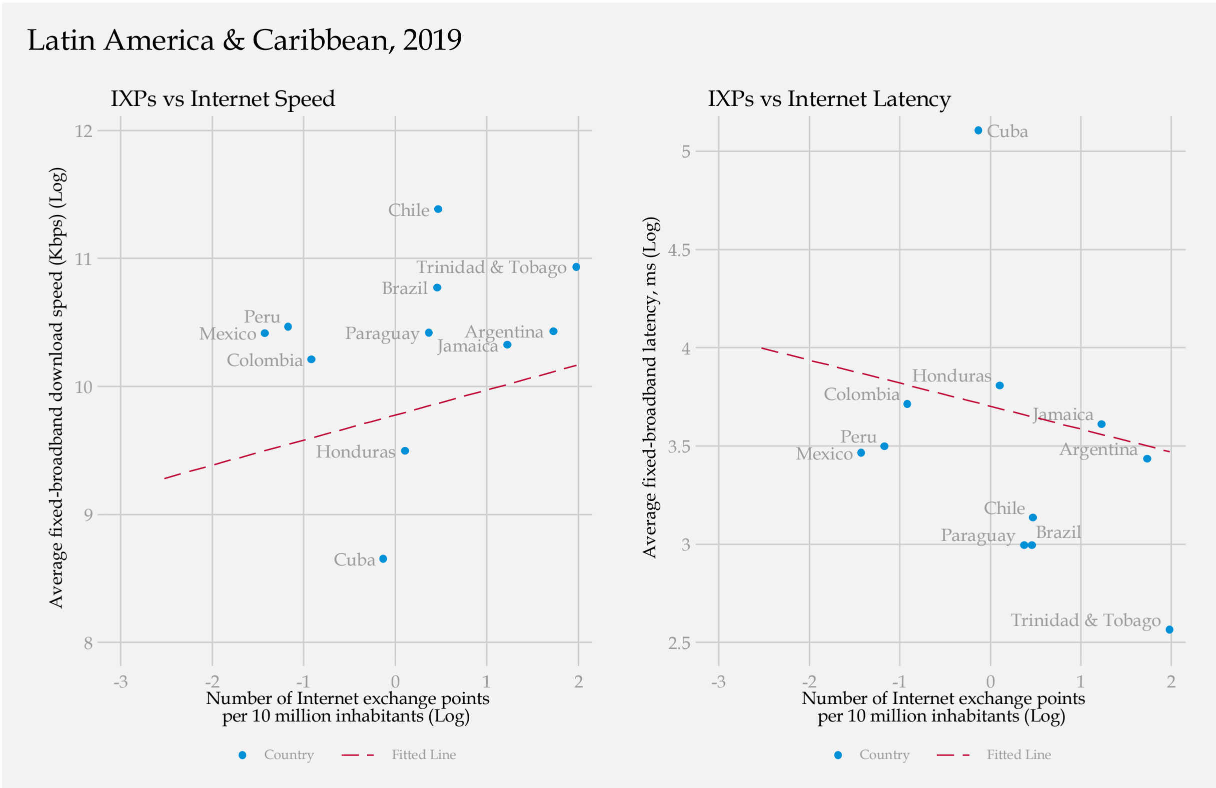
Figure 7: IXPs vs Fixed-broadband Speed and Latency, Europe 2019



Source: Produced by ESCAP based on data from the Economist Intelligence Unit's 'Inclusive Internet Index 2020', Online Database, available from: https://theinclusiveinternet.eiu.com/ (accessed 27 February 2020)

Annex 4

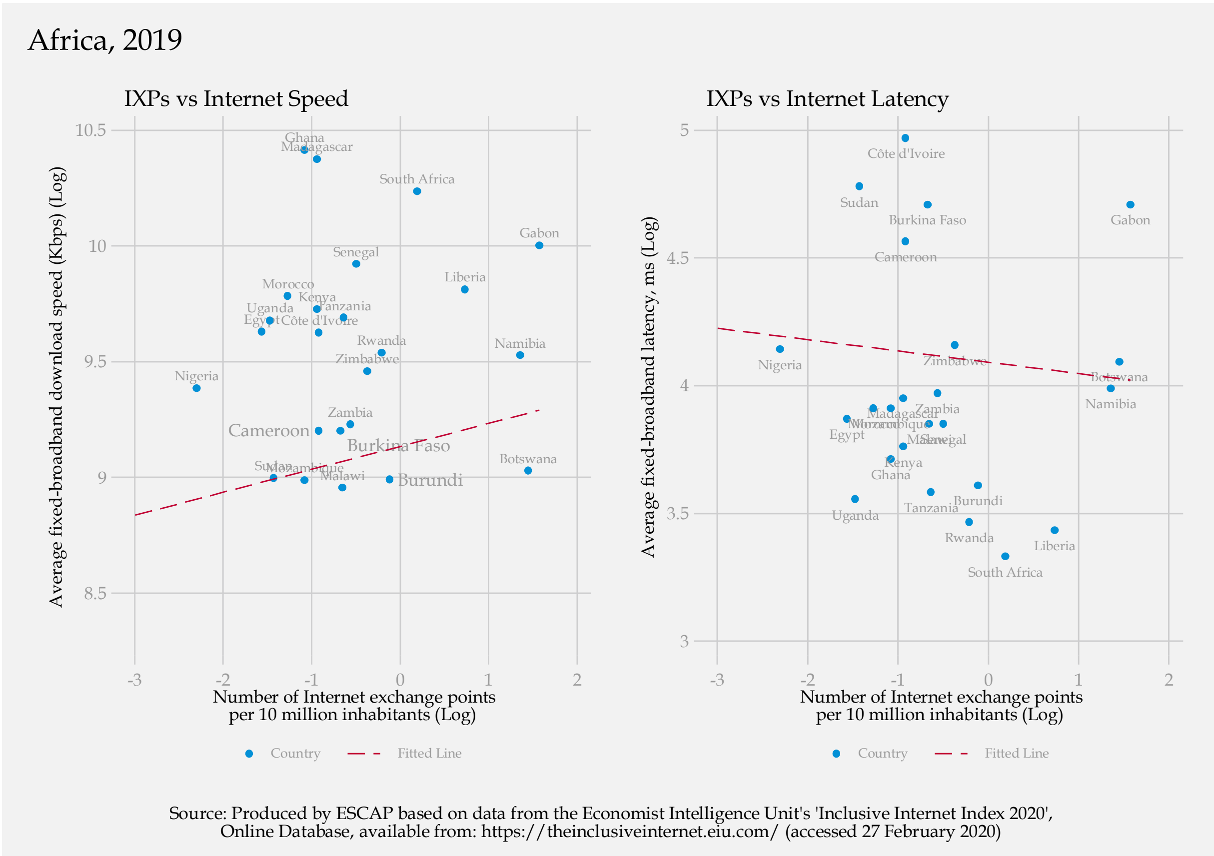
Figure 8: IXPs vs Fixed-broadband Speed and Latency, Latin America & Caribbean 2019



Source: Produced by ESCAP based on data from the Economist Intelligence Unit's 'Inclusive Internet Index 2020', Online Database, available from: https://theinclusiveinternet.eiu.com/ (accessed 27 February 2020)

Annex 5

Figure 9: IXPs vs Fixed-broadband Speed and Latency, Africa 2019



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