DO INTERNET EXCHANGE POINTS REALLY MATTER? EVIDENCE FROM BOLIVIA

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ABSTRACT

In this paper we study the impact of the implementation of an IXP in the city of La Paz, Bolivia. The case has some desirable characteristics. First, Bolivia ranks at or near the bottom of Internet development (however measured) in Latin America, and thus presents a fertile environment in which the benefits of an IXP should be readily observed. Second, the IXP emerged from a new interconnection regime that requires that large access providers exchange traffic locally through a single interconnection point. This is critically different from other scenarios in which IXP membership is voluntary, and thus its impact is highly dependent on which networks choose to participate.

Our impact evaluation strategy is twofold. First we analyze industry performance data collected by the Bolivian telecom authority. Second, we deploy active probes located in different network operators across Bolivia in order to obtain direct measurements about latency, the utilization of local routes, and other network performance metrics. These are combined with traffic indicators obtained from the IXP itself.

Our preliminary results suggest that PIT Bolivia has made a positive impact on network performance in Bolivia. More specifically, local traffic passing through PIT Bolivia exhibits significantly lower latency and fewer hops than local traffic routed over international transit links. However, because traffic levels at PIT Bolivia are low and growing slowly, the economic benefit to participating ISP, and therefore to the Bolivian Internet ecosystem as a whole, is more modest than predicted. Further, given existing Internet usage patterns that heavily favor content access, the current absence of CDNs at PIT Bolivia considerably limits traffic growth, thus reducing the potential impact of the initiative.

Keywords: INTERNET DEVELOPMENT, IXP, IMPACT EVALUATION, BOLIVIA.
1. INTRODUCTION

There is a growing literature suggesting that the presence of Internet Exchange Points (IXPs) promotes investments, reduces costs and increases the quality of Internet access services (Garcia-Zavallos et al., 2011; Kende and Hurpy, 2012; Clark et al., 2011; Sowell, 2013). Another strand of literature argues that IXPs are contributing to the flattening of the Internet architecture, weakening the relevance of top-tier backbone at the core of the traditional Internet hierarchy and therefore strengthening local network operators (Xu et al., 2004; Yoo, 2010; Weller and Woodcock, 2013). These benefits are hypothesized to be particularly relevant for developing countries, where network operators face higher transit costs and where investment incentives tend to be weaker.

Yet to date there has been little empirical testing of these claims. To our knowledge, the only studies that empirically examines the impact of IXPs on Internet growth in emerging countries are Kende and Hurpy (2012) and Katz et al. (2013). The first assess the evolution of IXPs in Kenya and Nigeria. It finds that in both cases the development of the IXP has led to significant reductions in latency and savings in transit costs for participating operators. Yet the study has many limitations, both in terms of methodological rigor (latency and cost indicators are not directly observed but rather reported by informants) as well as in the outcome variables under consideration. Katz et al. (2013) present an econometric model that seeks to estimate the effect of IXPs on retail broadband prices based on data for 10 Latin American countries for the 2010-2013 period. The findings suggest that the presence of an IXP is negatively correlated to the price of higher-quality services (above 3Mbps of advertised speed) but does not affect prices for entry-level services.

In this paper we seek to contribute to fill this gap by analyzing the impact of PIT Bolivia, the first IXP in the country which started operations in November 2013. Situated in the city of La Paz, PIT Bolivia was set up in response to a government mandate passed in October 2012, which required that Internet access providers with international connectivity exchange traffic locally through a single interconnection point. At present, six network operators are connected, all of which offer retail access services. Combined, they account for 88% of fixed broadband subscribers and the totality of mobile subscribers in Bolivia.
The case of PIT Bolivia has some desirable characteristics. First, Bolivia ranks at or near the bottom of Internet development (however measured) in Latin America (see section 2). It therefore presents a fertile environment in which the benefits of an IXP, if in fact true, should be more easily observed than in more mature markets. Second, as mentioned, PIT Bolivia is the result of a new interconnection regime which requires large access providers to exchange traffic locally through a single interconnection point. This is critically different from other cases in which IXP membership is voluntary, and therefore its impact is highly dependent on which networks choose to participate. As several authors argue (e.g., D'Ignazio and Giovannetti, 2009; Restrepo and Stanojevic, 2012), the incentives to participate in IXPs vary widely across network operators.

Our impact evaluation strategy is twofold. First we analyze industry performance data collected by the Bolivian telecoms authority as well as through other sources. Following the existing literature, we hypothesize that the IXP should result in lower access prices and increased service quality, which in the longer term should contribute to subscriber growth and accelerate investments in Internet-related infrastructure and services. Second, we deploy active probes located in different network operators across Bolivia in order to obtain direct measurements about latency, the utilization of local routes, and other network performance metrics. These are combined with traffic indicators obtained from the IXP itself.

Our preliminary results suggest that PIT Bolivia has made a positive impact on network performance in Bolivia. More specifically, local traffic (i.e., originating and terminating in a Bolivian IP prefix) passing through PIT Bolivia exhibits significantly lower latency and fewer hops than local traffic routed over international transit links. However, because traffic levels at PIT Bolivia are low and growing slowly, the economic benefit to participating ISP, and therefore to the Bolivian Internet ecosystem as a whole, is more modest than predicted. In fact, industry performance metrics show little variation within the (relatively short) period under study. Further, given existing Internet usage patterns that heavily favor content access, the current absence of CDNs at PIT Bolivia considerably limits traffic growth, thus reducing the potential impact of the initiative.

The paper is organized as follows. The next section provides an overview of the telecommunications market in Bolivia and highlights key facts that reveal the lag in Internet development in the country. Section 3 presents our methodology and hypotheses, and discusses key findings. The conclusion discusses the implications of
our findings both for policymakers as well as for future work about the potential of IXPs to spur Internet growth in emerging markets.

2. BACKGROUND AND CONTEXT

2.1. The Telecommunications Sector in Bolivia

Bolivia is a Mediterranean country with a low population density of about 9.7 people per km², with many isolated and small population centers. It is divided into nine departments, but three of them (Santa Cruz, La Paz and Cochabamba) concentrate about 70% of the Bolivian population. A third of its population lives in rural areas, and its territory extends from the Andes to the Amazon basin, thus presenting several challenges for infrastructure development and economic integration. Bolivia is one of the poorest countries in Latin America with a per capita income of USD 2868, about 43% of the regional average. However over the past decade it has greatly benefited from the boom in commodity prices (particularly natural gas and metals), growing at a healthy pace of between 4-5% every year.

The evolution of the telecommunications sector in Bolivia can be divided into three periods (Barja, 1999; Zalles Enriquez, 2008). The first extends from the introduction of fixed telephony in the country in the 1940s until 1994. This period is characterized by the presence of 15 local telephony cooperatives, which provided fixed telephony services in the nine departmental capitals and only about 26 smaller cities under monopoly conditions. Long-distance and international services were in turn provided by ENTEL, the state-owned incumbent. This industry structure was consolidated in the early 1960s and persisted almost unchanged for three decades. The exception was the introduction of mobile telephony in 1991 by TELECEL, a subsidiary of Millicom International.

The second period starts in 1994, when the government embarked on a large program of market-oriented reforms that included the partial privatization of ENTEL, among many other state-controlled assets. As in other Latin American countries, the privatization process was structured to attract foreign investment and management expertise, though in the case of ENTEL the state retained control of 50% of the newly created mixed-capital enterprise. In 1995 Telecom Italia acquired 50% of ENTEL for USD $610M. As part of this process, the government also extended ENTEL’s monopoly over long-distance and international services for six years, while local cooperative also benefited from a similar
extension of their monopoly license in their respective local services areas (Calzada and Davalos, 2005). A new regulator, SITTEL, was created to oversee the development of the industry under the new structure.

After the liberalization of the market in 2001, competition developed rapidly in long-distance and mobile services, but the local telephony market remained essentially unchanged. During this period investments in the telecommunications sector experienced a ten-fold increase, driven in large part by the newly (partly) privatized company. The mobile telephony market experienced rapid growth after the entry of two new market players: ENTEL Móvil (a subsidiary of ENTEL) in 1996, and Nuevatel in 2000, in which the local cooperative for the city of Cochabamba has a minority participation.

The third period starts in 2007, when under the leadership of President Evo Morales the government began reversing several of the market-oriented reforms implemented during the 1990s. The two most critical reversals were the renationalization of ENTEL in 2008 and the replacement of SITTEL with a new regulatory authority (currently Autoridad de Regulación y Fiscalización de Telecomunicaciones y Transportes, or ATT) which is directly dependent from the executive (more specifically the Ministry of Public Works, Housing and Services). Two years later, a new telecommunications law was passed. Among many other things, the new law requires that Bolivian ISPs exchange traffic through a single interconnection point located within the national territory (Art. 50). The implementation process of PIT Bolivia, as the interconnection point was named, was thus started from this legal mandate.

2.2. Internet in Bolivia: Key facts

Bolivia ranks at or near the bottom on multiple indicators of Internet development in Latin America. To a large extent this could be attributed to the economic, social and geographical endowments of the country as a whole. Previous studies have consistently found that income and education are among the strongest determinants of Internet penetration (among many others Chinn & Fairlie, 2010; Galperin and Ruzzier, 2013). For obvious reasons, the slow pace of growth in basic telecommunications infrastructure has also retarded the development of Internet services in Bolivia. Fixed telephony penetration (at 8.19 per 100 habitants in 2013, well below the region’s average of 18 lines per 100 habitants) is among the lowest in the region, and cable TV penetration is almost
negligible. Not surprisingly, until the introduction of mobile broadband services in 2006, the market for Internet access in Bolivia was a fraction of the market in neighboring countries.

Commercial Internet services were introduced in 1996 by BolNet, an offspring of an UN-funded project to connect universities and research centers across Bolivia to the Internet. A dedicated 64Kbps satellite link provided international connectivity to BolNet, which also administered the .bo ccTLD. By 2000 there were 12 ISPs in Bolivia, including three telephone cooperatives and mobile operator TELECEL. BolNet was later absorbed by ENTELnet, a subsidiary of the incumbent operator ENTEL, and the administration of the .bo ccTLD was transferred in 2002 to ADSIB (Agencia para el Desarrollo de la Sociedad de la Información en Bolivia), a government agency created to advance Internet services in Bolivia.

Bolivia is among the countries with the lowest broadband penetration in the region, as shown in Figure 1. Fixed broadband connections per capita are the second lowest in the region, while the performance in mobile broadband is only slightly better (fourth lowest in the region). As mentioned, much of its poor performance can be explained by the fact that Bolivia has the third lowest GDP per capita (adjusted for PPP) in the region, as shown in Figure 1 (secondary axis). Yet its performance is poor even when accounting for income differences, particularly in fixed broadband services. While its GDP per capita is about 43% of the regional average, its fixed broadband penetration is only 17% of the regional average. By contrast mobile penetration is 43% of the regional average, in line with GDP per capita.

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Sources: ITU and ATT.
After almost two decades fixed Internet services remain marginal in Bolivia (Figure 2). They account for less than 5% of all connections, while mobile connections account for the remaining 95%. Further, even though mobile telephony operators began deploying third-generation cellular services in 2008, GPRS/EDGE services still account for 60% of all mobile data connections in Bolivia. As a result, out of about 2.7M Internet connections in the country, less than half (42.7%) could be classified as broadband by year-end 2013. Nonetheless in early 2014 3G connections outnumbered GPRS/EDGE connections, marking an important milestone in the transition to higher-quality access services.

Sources: GSMA, World Bank and ITU.
A key explanation for the poor performance of fixed Internet services is the fact that prices in Bolivia are among the highest in the region. As shown in Figure 3, the average price (in USD) per Mbps of advertised download speed for fixed access in Bolivia is $78, over three times the regional average of $23.
Relative price performance in mobile broadband services is significantly better. As shown in Figure 4, the lowest price for a postpaid mobile broadband (3G or better) access plan with at least a 1GB data allowance is $14.1 USD, which is line with the regional average. Yet considering that GDP per capita is less than half of the regional average, affordability levels for broadband in Bolivia, even for mobile services, are among the lowest in the region.

Figure 3: Average price per Mbps (advertised download speed) in USD, 2Q2014
Quality indicators also highlight the challenges for Internet growth in Bolivia. The average advertised download speed for fixed Internet services in Bolivia (3.4Mbps) is the fourth lowest in the region, and only 20% of the regional average (Figure 5). Further, various indicators of actual delivered speed suggest that broadband quality in Bolivia is among the lowest in the region. For example, using data from Ookla’s Netindex, Figure 6 shows that average download speeds in Bolivia in August 2014 were between 30% (for fixed) and 45% (for mobile) of the regional average, and about ten times lower than regional leader Uruguay.
Figure 5: Average advertised download speed (in Mbps), 2Q2014

Source: CETYS.

Figure 6: Download speeds (Net Index) in Mbps, August 2014

Source: Ookla.
Another indicator of the limited development of Internet services in Bolivia is the small volume of content hosted locally. This is suggested by two indicators. First, Figure 7 shows the number of registered domain names in Bolivia (.bo), both in absolute terms (primary axis) and relative to population (in registered domains per 100 habitants). With only 9,169 registered .bo domain names for a population of about 10M, Bolivia has the third lowest number of registered ccTLD names per 100 habitants in the region.

![Figure 7: Number of registered ccTLD names, 2013](image)

Source: LACTLD.

Second, our findings suggest that the most popular websites in Bolivia are both registered and hosted outside the country. According to data from Alexia, in August 2014 only 15 of the top 100 visited sites from Bolivia were registered under a .bo domain name. In order to establish where these top 100 sites are hosted, we pinged them and checked whether the IP address corresponded to a block assigned to a Bolivian AS. As of August 2014 only 6% of the top 100 sites in Bolivia are hosted within the country, which suggests that much of the web traffic generated in Bolivia is internationally routed. Overall, the
picture that emerges from the data is that Bolivia is trapped in a low equilibrium characterized high Internet access prices, poor service quality, low adoption levels, and a small content-hosting market, all of which prevents achieving economies of scale and reinforces inefficiencies in traffic routing.

2.3. Competition and prices in retail Internet services

At first glance broadband markets in Bolivia are reasonable competitive. At the national level, the largest operator in the fixed access market is COTAS (local cooperative for the city of Santa Cruz) with a market share of 30%, followed by COMTECO (local cooperative for the city of Cochabamba) with 28%, ENTEL (16%) and private operator AXS (10%). However, effective competition is hindered by the very limited development of cable TV networks and the geographical dispersion of ADSL providers. In fact the only operator that offers broadband services in the nine departments is ENTEL, while AXS has partial coverage in the largest three cities (La Paz, Cochabamba and Santa Cruz). With the exception of the capital city of La Paz, incumbent operators (the local cooperatives) have effectively leveraged their dominance of the PSTN into the fixed broadband market. Competition is healthier in mobile broadband services, with the three operators offering services across the Bolivian territory. TELECEL dominates the market with 52% of all mobile broadband connections, followed by NUEVATEL (28%) and ENTEL (20%).

Entry-level subscription prices in fixed broadband have fallen on average 39% between 2009 and 2013, while in the mobile broadband segment monthly subscription prices dropped at a significantly faster rate of 61% during the same period (Figure 8). Yet the key adoption driver has been the introduction of prepaid, daily data plans by mobile operators in mid-2011, which has significantly lowered entry barriers for the majority of Bolivians. For example, daily data plans (with a 50MB data cap) can be currently purchased for as little as BOB $5 (about $0.70 USD), while the basic mobile broadband monthly subscription (1GB data cap) starts at BOB $50 (about $7 USD). For comparison, the basic fixed broadband subscription (with a modest 425 Kbps of advertised download speed) costs over three times as much (BOB $178, about USD $26). On an annual basis this represents about 12% of gross income per capita in Bolivia, which helps explain why fixed broadband connections remain marginal.
Some observers (e.g., OECD, 2014) point out to geography as a key challenge for Internet growth in Bolivia. As a Mediterranean country without direct access to submarine cables, Bolivian ISPs face higher backhaul costs, since data traffic needs to be routed across borders through a terrestrial transport network in order to reach either the Atlantic or the Pacific coast of South America. ENTEL owns and operates the most extensive terrestrial network in Bolivia, with a fiber ring that connect the three largest cities (La Paz, Santa Cruz and Cochabamba) and connects to international backhaul providers in Peru (Desaguadero), Chile (Tambo Quemado) and Argentina (Yacuiba). Figure 9 shows ENTEL’s fiber network and its international gateways, while Figure 10 shows the access routes to submarine cables. Other operators either buy capacity from ENTEL or have shorter fiber segments connecting to any of these international gateways.

2.4. The IP transit market

Source: ATT.
Figure 9. ENTEL’s terrestrial fiber network

Source: ENTEL.

Figure 10: ENTEL’s international gateways

Source: ENTEL S.A.
The most competitive prices are obtained in the route via Tambo Quemado, which connects to the landing point of two submarine cable in Arica in the Pacific coast of Chile. There are several international transit providers offering services to Bolivian ISPs. Yet prices are among the highest in the region. Table 1 shows that while median IP transit prices per Mbps/month in the largest capitals in the region hover in the USD $25 range, ISPs in La Paz face transit costs that are as much as eight times higher. Moreover, transit costs in Bolivia are falling are at a slower pace than other countries, which aggravates the observed price gap.

Table 1: Median IP transit prices per Mbps/month in USD, 2009-13

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>CAGR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buenos Aires</td>
<td>42</td>
<td>39</td>
<td>27</td>
<td>25</td>
<td>-12%</td>
</tr>
<tr>
<td>Lima</td>
<td>65</td>
<td>48</td>
<td>35</td>
<td>35</td>
<td>-14%</td>
</tr>
<tr>
<td>Mexico City</td>
<td>40</td>
<td>28</td>
<td>8,5</td>
<td>6,3</td>
<td>-37%</td>
</tr>
<tr>
<td>Rio de Janeiro</td>
<td>48</td>
<td>41</td>
<td>27</td>
<td>25</td>
<td>-15%</td>
</tr>
<tr>
<td>Santiago</td>
<td>47</td>
<td>40</td>
<td>29</td>
<td>25</td>
<td>-15%</td>
</tr>
<tr>
<td>Sao Paulo</td>
<td>50</td>
<td>39</td>
<td>27</td>
<td>27</td>
<td>-14%</td>
</tr>
<tr>
<td>La Paz</td>
<td>n/a</td>
<td>251</td>
<td>238</td>
<td>186</td>
<td>-10%</td>
</tr>
</tbody>
</table>

Source: Telegeography/ATT.

Contracted Internet international capacity has risen steadily in Bolivia in the past years, following the rapid growth in mobile broadband subscribers since 2010. As shown in Table 2, the pace of growth in contracted international bandwidth in Bolivia is among the fastest in the region.
Table 2: International Internet bandwidth in Gbps, 2009-13

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>CAGR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolivia</td>
<td>308</td>
<td>664</td>
<td>832</td>
<td>1340</td>
<td>1835</td>
<td>43%</td>
</tr>
<tr>
<td>Brazil</td>
<td>743</td>
<td>1114</td>
<td>1625</td>
<td>2557</td>
<td>3721</td>
<td>38%</td>
</tr>
<tr>
<td>Chile</td>
<td>249</td>
<td>597</td>
<td>684</td>
<td>1049</td>
<td>1343</td>
<td>40%</td>
</tr>
<tr>
<td>Colombia</td>
<td>167</td>
<td>261</td>
<td>417</td>
<td>563</td>
<td>711</td>
<td>34%</td>
</tr>
<tr>
<td>Ecuador</td>
<td>8</td>
<td>24</td>
<td>51</td>
<td>68</td>
<td>98</td>
<td>65%</td>
</tr>
<tr>
<td>Mexico</td>
<td>324</td>
<td>537</td>
<td>845</td>
<td>1413</td>
<td>1999</td>
<td>44%</td>
</tr>
<tr>
<td>Panama</td>
<td>138</td>
<td>216</td>
<td>246</td>
<td>291</td>
<td>325</td>
<td>19%</td>
</tr>
<tr>
<td>Peru</td>
<td>451</td>
<td>456</td>
<td>385</td>
<td>493</td>
<td>741</td>
<td>10%</td>
</tr>
<tr>
<td>Venezuela</td>
<td>71</td>
<td>113</td>
<td>198</td>
<td>270</td>
<td>322</td>
<td>35%</td>
</tr>
</tbody>
</table>

Source: Telegeography/ATT.

Yet at 36Gbps Bolivia’s overall international Internet connectivity capacity remains very low both in absolute and relative terms. As Figure 11 shows, one Mbps of international capacity is shared among approximately 110 Internet users in Bolivia (primary axis in Gbps), while in the better connected countries in the region (e.g., Panama or Chile) it is shared by as few as 6 users (the regional sample average is 35).
The economics of the IP transit market are such that low contracted volumes are strongly associated with higher per unit costs. International transit is therefore a significant cost factor for Bolivian ISPs. A precise estimation of this cost factor is difficult given that contracted international bandwidth is shared across many of the services provided by telecom operators. The case of AXS provides the best approximation since its core business are Internet access and other data services. In the first semester of 2013 international transit costs represented 38% of total operating costs for AXS. The figure is significantly lower for other operators whose revenues are based on traditional telephony services. Yet the cost impact is still significant, for example in the case of COTERI (small local cooperative in Northeast Bolivia), for which international transit represents 11% of total operating costs. For larger operators such as COTAS (local cooperative for Santa Cruz) the figure drops to about 6% of total costs. Yet if calculated as a percentage of revenues from data services (including Internet access), international transit costs climb to 24% for COTAS and 18% in the case of ENTEL.3

Given that the growth in contracted international capacity (57% CAGR in 2010-13) has far outpaced the drop in prices over the same period (-10% CAGR), the overall amount paid by Bolivian ISPs in international transit costs (primary axis) has been rising on a yearly basis (Figure 12). On aggregate, Bolivian telecom operators paid about USD 6.9M in international transit in 2013. Reducing these costs has been one of the major drivers behind the PIT Bolivia initiative.

3 All figures are based on financial data provided by operators and collected by ATT.
3. CASE STUDY DESCRIPTION AND FINDINGS

3.1. PIT Bolivia

The IXP in Bolivia differs substantially from most other cases in the region in terms of its origins and legal framework. Following the European model, most IXPs in Latin America are operated as non-commercial organizations administered by its members or under the umbrella of trade associations (Galperin, 2103, Katz et al., 2013). They emerged as a collective response by ISPs to the challenges of growing traffic demand and the slow liberalization of telecommunications markets, which created bottlenecks in international connectivity and high prices for national data transport. Until recently, governments in the region have for the most part stayed away from legislating Internet traffic exchanges. The only significant exception is Chile, where in 1999 the regulator required that ISPs implement the means to exchange traffic locally, although the legislation did not
specifically favor neutral exchange points.\textsuperscript{4} As a result IXPs in Chile are operated by large ISPs themselves as part of their co-location business.

By contrast, the origins and legal framework of PIT Bolivia are strongly associated with the reforms in the telecommunications industry brought about by the government of President Morales since 2008. As discussed, in 2011 a new telecommunications law was passed that required Bolivian ISPs to exchange traffic through a single interconnection point located within the national territory. The requirement was further specified by Presidential Decree 1391 of October 2012, which among other things limited the obligation to ISPs with direct connections to international backhaul providers (thus excluding most small and medium-sized operators). In March 2013 the Deputy Minister of Telecommunications set the basic parameters for the operation of PIT Bolivia. Most significantly, it established: a) that the new IXP would be funded exclusively through membership fees, and that these fees should reflect either the traffic routed or the link capacity of each member; and b) that ISPs must peer with each other under non-discriminatory conditions.

In August 2013 ATT passed an administrative resolution that contained the basic outlines for the implementation of PIT Bolivia. The resolution established:

- that the membership of PIT Bolivia will be open to all network operators within the Bolivian territory (though mandatory only for those with international capacity);

- that PIT Bolivia will be administered by a Technical Committee composed by representatives from ATT, FECOTEL (the industry association of telephone cooperatives), CATELBO (a telecom industry group which includes private operators, large cooperatives and ENTEL), ADSIB and ENTEL;

- that PIT Bolivia will initiate operations with nodes in the cities of La Paz, Cochabamba and Santa Cruz, with ENTEL providing the appropriate physical spaces;

\textsuperscript{4} SUBTEL Resolution 1483 of October 1999.
- that participating ISPs must necessarily enter into peering agreements with all other connected operators – in other words, it required mandatory multilateral peering.

PIT Bolivia was thus created by government fiat, and government representatives are directly involved in its operations, through either ENTEL or government agencies (ATT and ADSIB). Most critical, government representatives hold a voting majority (three out of five) within the Technical Committee. In addition, ENTEL is required to provide physical spaces for PIT Bolivia, which has further created concerns about its neutrality vis-à-vis the rest of the market players.

Operations effectively started in November 2013, with six operators connected to a single Ethernet switch through 1Gbps ports: ENTEL itself, the two largest cooperatives (COMTECO and COTAS), private operator AXS, and mobile operators NUEVATEL and TELECEL. As of August 2014, membership has remained unchanged. Further, even though the original regulatory mandate required interconnection nodes in the three largest cities, as of August 2014 only the La Paz node is operational, located within ENTEL premises. This is clearly not optimal given that only about 27% of Internet subscribers in Bolivia reside in the La Paz area, with Santa Cruz and Cochabamba accounting for the 34% and 17% respectively.

3.2. Methodology and hypotheses

The theoretical case for IXPs is well established in the literature (Kende and Hurpy, 2012; Chatzis et al., 2013; Weller and Woodcock, 2013). In order to respond to growing traffic demand while keeping transit costs under control, ISPs have adopted new interconnection strategies. One of these strategies has been the expansion of no-cost peering agreements with other local network operators at neutral co-location sites. The decision to peer at a common co-location site, rather than to establish bilateral links, relates to a number of factors, including lower transaction costs, lower risks associated with sunk investments, and the network externalities generated by IXPs (Xu et al., 2004; Ager et al., 2012; Restrepo and Stanojevic, 2012; Sowell, 2013).
According to previous studies, the two key benefits associated with the expansion of IXP are the lowering of transit costs and the drop in latency, which increases service quality. Lower costs are associated with the minimizing of tromboning, a practice whereby adjacent ISPs exchange traffic over international transit routes provisioned by third-party operators. This is particularly problematic for ISPs in developing countries, which often face high international transit costs, as is the case of Bolivia. Quality improvements are associated with the reduction in distance and the number of hops for data packets traveling between peering parties, which helps lower latency and jitter, thereby improving network performance. Other benefits include increased network reliability (because of increased route redundancy), more efficient technical coordination between network operators, better bargaining terms with upstream transit providers, and increased incentives for participating operators to invest in their own network infrastructure.

Following these arguments, and given the lag in the development of Internet infrastructure and services in Bolivia discussed in previous sections, we hypothesize that PIT Bolivia should promote Internet growth in several ways. The positive impact on network performance in national routes (i.e., originating and terminating in Bolivia) can be stated as follows:

- **H1**: Roundtrip time (RTT) will be lower in national routes passing through PIT Bolivia than in national routes not passing through PIT Bolivia.
- **H2**: The number of hops in national routes passing through PIT Bolivia will be lower than in national routes not passing through PIT Bolivia.

H1 and H2 are associated with network latency. If both are true, lower latency in national routes should increase incentives to host content locally, thereby increasing demand for local domain names. Therefore,
H3: Given constant registration prices, the number of registered .bo domain names will increase discontinuously following the growth in traffic at PIT Bolivia.

In addition, the growth in traffic exchanged at PIT Bolivia is expected to reduce international tromboning and create incentives to localize international content, therefore generating savings in IP transit costs for participating ISPs. The magnitude of these savings as well as the extent to which these savings will be passed on to consumers in the form of lower prices and/or better quality services depends on several factors. Based on previous studies undertaken in countries with low or moderate levels of Internet development (e.g., Kende and Hurpy, 2012; Katz et al., 2013), and given the moderate level of competition observed in Internet retail services in Bolivia, we hypothesize that at least some of these cost savings will be passed on to consumers. Therefore,

- H4: Ceteris paribus, retail prices for Internet access will decrease discontinuously following the growth in traffic at PIT Bolivia.

- H5: The advertised download speeds offered by ISPs in Bolivia will increase discontinuously following the growth in traffic at PIT Bolivia.

In order to test these hypotheses we gather and analyze two types of data. First, we analyze industry performance data collected by the Bolivian telecom authority and ADSIB. All registered ISPs in Bolivia are required to submit detailed reports about prices, number of subscribers by location and technology, cost and amount of international bandwidth purchased, and several other performance indicators to ATT on a quarterly basis. Based on these reports we built time series of key indicators of industry performance, which allows for the identification of trends before and after PIT Bolivia started operations (November 2013). In addition, we obtained data from PIT Bolivia, which allows monitoring of the traffic exchanged at the IXP.

Second, we developed a network-testing platform consisting of a dozen probes distributed among different access providers across Bolivia. Each of the probes (a Linux-based Raspberry Pi) contains PladMed, a custom-developed testing software with several broadband quality test tools. PladMed’s basic test tool uses the ping and
traceroute commands to measure two basic parameters: latency (measured in RTT) and distance (measured in number of hops). The commands are sent from PladMed to every /24 prefix allocated to Bolivia, at a rate of about one test per hour. Therefore, each observation corresponds to a test between a PladMed probe and a /24 prefix in Bolivia, and the results reported are the measurements obtained from each of these test routes.5

3.3. Preliminary results

At the time of writing (August 2014) the testing platform was in its beta phase. The results reported correspond to a single probe within ENTEL’s network for a period of 8 weeks (June 15 – August 10). Following the stated hypotheses H1 and H2, the measurements obtained were divided into the following four categories:

a) PIT routes: test routes that include an IP address assigned to PIT Bolivia. This corresponds to traffic routed through PIT Bolivia;

b) P2P routes: test routes that do not include an IP address assigned to Bolivia but also do not include an IP address outside Bolivia. This corresponds to either direct links between Bolivian operators or routes within a single network;

c) International routes: routes that include an IP address not assigned to Bolivia. This is tromboned traffic through international transit routes (most of it routed through NAP Americas in Miami);

d) Anomalous routes: routes that include an IP address assigned to PIT Bolivia but that also include an IP address outside Bolivia.

In the two-week observation period reported, we obtained 641,401 observations. As Table 3 shows, the majority of observations resulted in routes passing through PIT Bolivia, as in fact required by law. Yet a significant number (about 11%) are still routed through international transit links. Anomalous routes amount to a very small fraction (about 0.1%), and are therefore eliminated for simplicity. Overall, these results suggests

5 Due to the widespread use of NAT among ISPs in Bolivia, we measure from our probe to the next-to-last hop.
that PIT Bolivia has significantly changed traffic patterns in the country, as operators use these new peering links to route the majority of traffic that originates and terminates in Bolivia.

Table 3: Observations by route category (June 15 – August 10)

<table>
<thead>
<tr>
<th></th>
<th>PIT routes</th>
<th>P2P routes</th>
<th>International routes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td># observations</td>
<td>512,575</td>
<td>58,513</td>
<td>69,520</td>
<td>640,608</td>
</tr>
<tr>
<td>%</td>
<td>80.0%</td>
<td>9.1%</td>
<td>10.8%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Annex 1 shows the dynamics of traffic at PIT Bolivia per ISP since the start of operations. Overall traffic levels are still modest, and differ significantly by operator. ENTEL exchanges an average of about 79Mbps, while other operators are in the 9Mbps to 48Mbps range (Annex 1). Total peak traffic in May 2014 (last available data) was about 280Mbps. Put into context, this traffic level is similar to that of IXPs in Mar del Plata (Argentina) or Campina Grande (Brasil), both medium-size cities with populations of about 650.000 inhabitants (less than 7% of Bolivia’s 10M). A patterns of traffic growth is observable in the case of ENTEL and AXS but not for other operators. Given the capacity of ports and links to PIT Bolivia, the traffic data suggests that the IXP infrastructure is underutilized.

Figure 13 shows the RTT results obtained from the 640,608 observations collected during the current beta-test phase. The findings suggest that PIT Bolivia has significantly reduced latency for routes originating and terminating in Bolivia. The median RTT in routes through PIT Bolivia was 39.9 ms, compared to 45.4 ms for P2P routes and 137.6 ms for international routes. In other words, localizing national routes resulted in a drop in latency of about 70%.
Similar results were obtained for distance, measured in number of hops. As Figure 14 shows, in routes through PIT Bolivia the median number of hops was 12.6, compared to 17 in international routes, a drop of about 26%. As expected, in routes within a single network or through direct links between operators the number of hops is lower (the median is 8.1). Overall, the results suggest that PIT Bolivia has helped improve the quality of services by significantly reducing latency and distance in national routes. This traffic, which in the past was for the most exchanged through international transit agreements, is now exchanged within Bolivia more efficiently at a significantly lower cost.
Figure 15 shows the evolution of registered .bo domain names. The evidence does not support H3, since no acceleration in the demand for local domain names is observable. It is worth mentioning that registration prices have stayed constant throughout the 2012-2014 period at BOB 280 (about USD 40).

Source: LACTLD
Given the low traffic volumes exchanged to date at PIT Bolivia, the cost savings in international bandwidth for participating IXPs are not yet significant. For example in the case of ENTEL (which has the highest traffic volume at PIT Bolivia), the operator has contracted international capacity for about 9Gbps, and is exchanging an average of about 79Mbps at the IXP. Therefore the potential savings represent less than 1% of the total contracted capacity. As several studies argue, given existing Internet use patterns (which increasingly favor video streaming and other content properties), it is critical for IXPs to attract peering from large CDNs as a way to boost traffic and create significant cost savings for participating operators. Until PIT Bolivia is able to attract such operators, its impact on ISPs’ cost structure, and therefore on access prices and other key industry indicators, will likely be very modest at best. Thus at this juncture we do not seek to test hypotheses H4 and H5.

4. CONCLUSIONS
REFERENCES


Annex 1: Daily traffic at PIT Bolivia by ISP