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Strategic choice and broadband divergence in the transition to next generation networks: Evidence from Canada and the U.S.

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ABSTRACT

This article investigates how infrastructure competition among broadband network infrastructure operators in Canada and the U.S. has influenced their incentives to increase fixed broadband connection speeds and invest in next generation fiber-to-the-premises (FTTP) technologies. The evolution of measured broadband speeds since the late 2000s documents growing differences in the incentives of dominant broadband operators to respond to demand for higher speed connectivity by increasing connectivity speeds they deliver to their customers. Dominant network operators in Canada have shown relatively stronger incentives than their counterparts in the U.S. to invest in and increase the capacity of legacy platforms. In the U.S. FTTP deployment incentives have been somewhat stronger, but network operators have been more reluctant to upgrade legacy technologies to deliver higher speeds. Diversity of strategic choices by large operators helps explain increasing regional and local broadband infrastructure gaps within the two countries. A high dividend payout financial strategy and increasing vertical integration appear to enhance the potential for overinvestment and inefficient duplication in legacy platforms by competing infrastructure providers.

1. Introduction

In response to rapidly growing demand for high-speed (broadband) Internet connectivity, network operators in some high-income countries and regions have deployed very-high capacity fiber-to-the-premises (FTTP) broadband technologies. In most other countries, network investments have primarily been allocated to upgrading the capacity of legacy copper networks. For operators that have made substantial investments to upgrade existing copper telephone or cable TV networks to enable the delivery of high-speed connectivity, incentives to deploy next generation fiber access technologies can be limited. This article identifies and evaluates distinctive paths of infrastructure competition arising from the strategic choices of dominant broadband infrastructure operators in Canada and the U.S., two relatively mature markets where access to high-speed connectivity on legacy platforms is near ubiquitous, but deployment of very-high capacity FTTP lags the OECD average (Fig. 1).

Broadband Internet access services delivered on a "best effort" basis via legacy copper and cable networks offer sufficient capacity for basic applications such as email and simple web browsing.[1] However, competition and innovation in the global market for advanced applications in the past few years have created strong demand for higher capacity fixed and mobile network resources that can offer

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[1] Most retail Internet services are advertised on the basis of maximum speed on a "best effort" basis. Best effort means that operators do not guarantee connection quality or a minimum speed. Particularly with DSL, the gap between advertised best effort speeds and actual speeds rises rapidly with distance from the fiber node.

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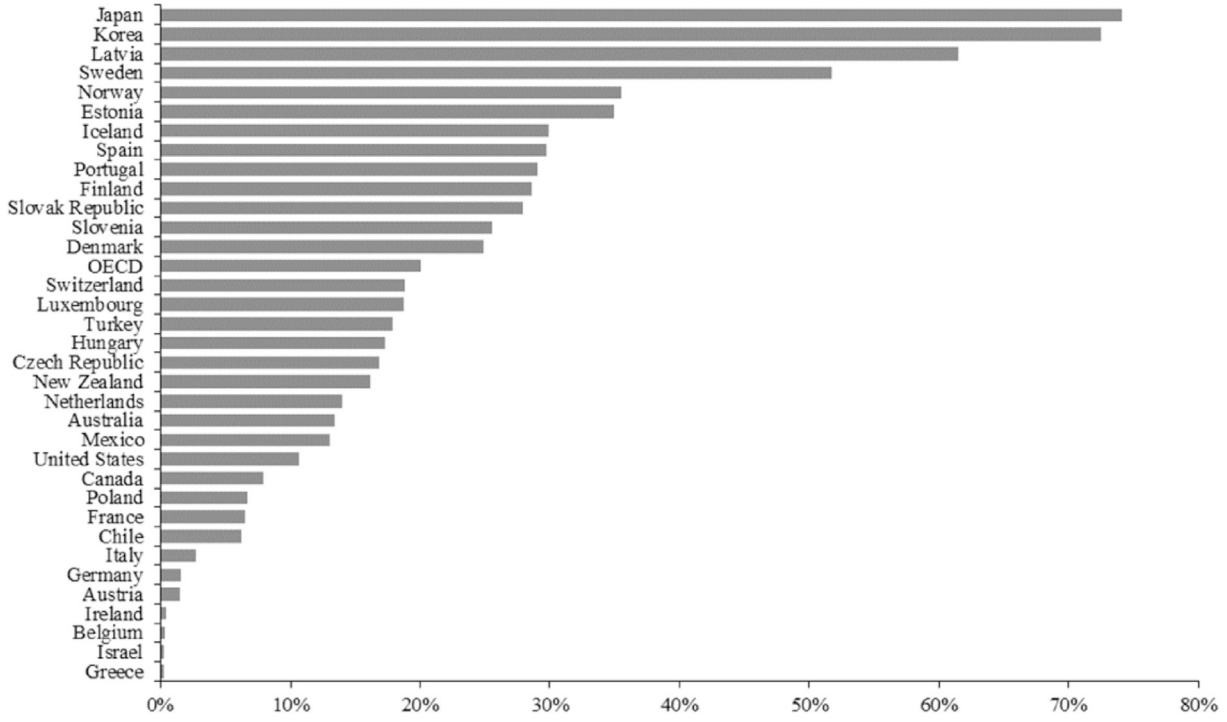

Fig. 1. Diffusion of Fiber Access Networks in High Income Countries (Percentage of fiber connections in total broadband subscriptions (OECD Broadband Statistics, Table 1.10, June 2016)).

more symmetric connections and minimum reliability standards. The extent to which legacy fixed broadband (i.e. copper/DSL, cable) infrastructure that supported the first stages of the development of the digital economy in the 1990s and 2000s can handle rapidly growing demand for more reliable and symmetric connectivity remains unclear but the capacity of next generation fiber-to-the-premises (FTTP) broadband networks to overcome the scalability and service quality limits of legacy broadband platforms is well understood.[2] However, incentives for private sector providers to transition from sunset (i.e. legacy copper and cable) to sunrise (i.e. FTTP) broadband platforms vary significantly across countries, as indicated by the percentage of FTTP connections among broadband subscriptions across the OECD (Fig. 1).

A handful of countries have experienced the fast uptake of FTTP (e.g. Japan, Korea, Sweden), but across the OECD more than 75% of broadband subscribers continue to rely on legacy DSL and cable platforms for their connectivity.[3] While the quality of experience on legacy platforms might be adequate for some users who are late adopters of more advanced and network intensive Internet applications and services, adopting these applications increasingly requires access to more symmetric and reliable connectivity that is hard to deliver on legacy technologies. As such, legacy platforms can be insufficient for the needs of early adopters of advanced applications, such as younger users and businesses. In markets where FTTP connections are not yet available (or affordable), demands placed on the legacy infrastructure by advanced users can have a significant negative externality on service quality experienced by others in the vicinity due to the congestion-prone DSL and cable networks in use. In markets where FTTP connections are available and in use (e.g. Japan and Korea), service quality is improved and the additional incremental cost for 1 Mbps (i.e. for a faster connection) tends to be substantially lower, meaning that broadband service is more affordable there than in countries where most end users have had little option but to rely on legacy DSL and cable network (e.g. The U.S., Canada, see Bischof, Bustamante, & Stanojevic, 2014).[4]

It is evident however that private sector incentives to decommission legacy technologies and extend FTTP connectivity have been limited in many high-income countries. This appears to be particularly the case in relatively mature markets where broadband adoption is already widespread and operators of legacy platforms have previously invested heavily in upgrading the capacity of their copper and

[2] A number of technological developments such as G.fast and DOCSIS 3.1 allow operators of copper-based platforms to deliver higher connection speeds on legacy platforms and have narrowed the gap with optical networks. Nonetheless, optical networks have a higher upside potential as they are cheaper to scale in response to demand growth, offer more symmetric speeds and the delivery Quality of Service (QoS) guarantees than is possible with xDSL or DOCSIS upgrades to legacy copper access networks. Due to these competing considerations, the choice between upgrading to legacy platforms to G.fast/DOCSIS 3.1 versus deploying fiber all the way to user premises is difficult one. See e.g. Maes, Guenach, Hooghe, & Timmers, 2012; Afflerbach, DeHaven, Schulhof, & Wirth, 2015; Franken, 2016.

[3] OECD Broadband Statistics, Table 1.3. OECD fixed and mobile broadband subscriptions, by technology, June 2016.

[4] Bischof et al., 2014, Fig. 10, p. 81.

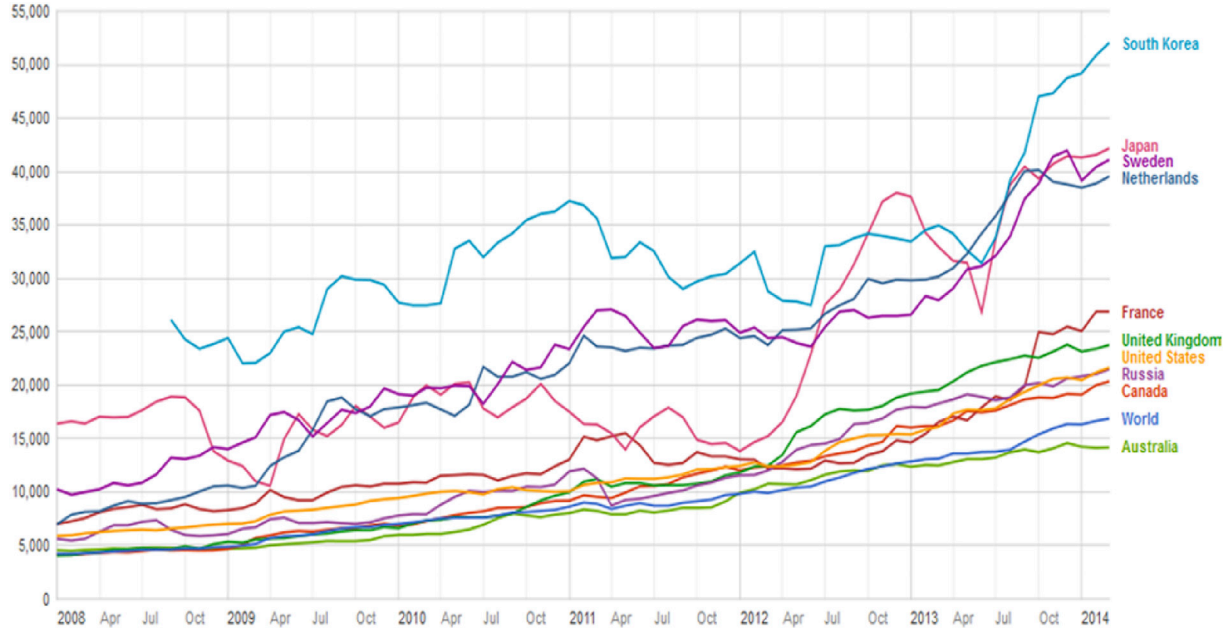

Fig. 2. Divergence of Broadband Service Quality (upper bound of average measured download speeds in Kbps. Source: Speedtest/Ookla, Google Public Data Explorer).

cable networks (i.e. VDSL/FTTN, DOCSIS).[5] In these markets, free cash flows (FCF) generated from past investments in legacy technologies (a practice known as "sweating the copper") compound barriers posed by the fixed costs in deploying next generation FTTP networks; in that these FCFs would have to decline and capital intensity of operators would have to increase to enable customer migration from the legacy technologies to FTTP.[6] The existence of a substantive gap between private and social returns to FTTP deployments is a key driver of calls for municipal fiber initiatives in relatively mature markets where high speed connectivity is already available via legacy copper-based "last mile" access networks (Nevo, Turner, & Williams, 2016; Wilson, 2017).[7]

In the short to medium term, a strategy of extending returns from past capital expenditures (capex) by cable bonding, hybrid fiber-copper, and squeezing out the last years of the copper local loop (e.g. G.Fast, DOCSIS 3.1) might therefore appear optimal to operators of these networks. This strategy has also proven to be successful in enabling some legacy network operators to divert cash flows from wireline investments to mobile network deployments and non-network assets in vertically integrated content and media markets.[8] Nevertheless, in the longer term such a strategy makes it increasingly expensive to scale fixed network capacity to growing demand and improve service reliability relative to fiber-based access platforms. Strategic choices by large operators determine their pace of creative destruction from legacy to FTTP technologies and partly explain growing gaps in broadband service quality, as proxied by measured speeds these operators deliver their customers in advanced economies (Fig. 2).

Beside the strategic choices of operators, other factors such as economic endowments, regulatory institutions, consumer preferences, and the design of public policy are likely to have an impact in explaining why some countries are further along in the transition to next generation FTTP networks while in others private sector incentives to deploy such networks have been negligible. At the same time, operators that have determined it is in their best interest to continue to "sweat the copper" in the last mile have strong economic incentives to resist the adoption of any public policies that may enhance FTTP deployment incentives (e.g. municipal fiber (Wilson, 2017),

[5] Although there are disincentives to extend FTTP connectivity where DSL and/or cable operators have upgraded their networks to deliver higher download speeds, it is relevant to note that there are significant benefits that can accrue to incumbents from decommissioning legacy technologies such as copper loops and other network assets that support the provision of universal access to Public Switched Telephone Networks (PSTN). In addition to lower costs of maintenance and provisioning on fiber access networks compared to the copper infrastructure, they also provide higher revenue potential for operators from higher speed/quality services and potential to offer value added services on top of them (e.g. triple play of Internet access, voice, and TV, and increasingly so-called Internet of Things (IoT) applications).

[6] For example, according to recent estimates by Deloitte, expanding "deep fiber" in the U.S. will require between $130 to $150 billion in capital expenditures. See: http://www.prnewswire.com/news-releases/deloitte-us-investment-of-130b-to-150b-in-deep-fiber-infrastructure-required-to-lead-global-digital-economy-opportunity-300480135.html.

[7] Attempts by local communities and municipalities to deploy next generation fiber networks as a complement to other public utilities they deliver or through public-private partnerships face significant resistance from incumbent operators of DSL and cable networks in North America. In the U.S. for example some states have prohibited municipalities from deploying or expanding public fiber networks. See e.g. State of Tenn. v. Fed. Commc'n Comm'n, No. 15–3291 (6th Cir. 2016).

[8] 4G wireless networks are increasingly offering higher speeds and tend to be less capital intensive than fixed fiber network deployments. "All in" wireless strategies of large incumbents such as Verizon and AT&T or Bell and Telus in Canada partly explain their apparent disincentives to deploy FTTP in order to be able to better compete with relatively faster cable fixed broadband operators. It is not clear if these strategies are efficient or viable. See Webb (2016). Compared to Canadian cable operators, U.S. cable operators have been more reluctant to invest in wireless, at least until recently. Increased investment by cable companies on wireless will likely have a negative impact on their ability to improve fixed network capacity and service quality in the future.

specialization through structural separation (Bruno, 2012), or essential facilities obligations (Bourreau, Cambini, & Doğan, 2014; Rajabiun & Middleton, 2015a), etc). Where these resistance efforts are successful, the pace of progress from sunset to sunrise platforms can become very slow. As in many other areas of technological change in the presence of networked behavior, the experience in the transition from legacy to next generation broadband technologies suggests a stable low-diffusion FTTP equilibrium exists and can persist (Jackson & Yariv, 2007).

Recognizing the potential for market failures in the adoption of new technologies and the need to incentivize investments in scalable FTTP infrastructure, various governments around the world have adopted policies that aim to promote fixed cost sharing and service-based competition, including by requiring operators of essential facilities (i.e. those that are non-duplicable or inefficient to duplicate) to provide third parties wholesale access at a price that limits incentives to overinvest in legacy and underinvest in next generation fiber access networks. Even though their policy frameworks are distinct, Japan and Korea can be viewed as examples of this class of countries (Choi, 2011; Minamihashi, 2012). In Europe, aggregate telecom investment tends to be lower in countries with more intensive and complex regulatory regimes (Grajek & Röller, 2012), but FTTP penetration and measured broadband speeds tend to be higher in countries that have been more successful at promoting service-based competition in the retail market for the provision of broadband services (European Parliament, 2016; Rajabiun & Middleton, 2015b).

In Canada, having initially replicated the U.S. strategy of forbearing from mandated third party access to next generation fiber networks, the Canadian Radio-television and Telecommunications Commission (CRTC) recently recognized the ineffectual nature of this approach to promoting investment in FTTP. In 2015 it reversed course and instituted a technologically neutral wholesale access policy that includes next generation FTTP networks (Telecom Regulatory Policy CRTC 2015-326). Although the CRTC has not yet explicitly implemented this regulatory policy, committing to a wholesale pricing model that offers a high expected mark up over costs on higher speed connections appears to have promoted the incentives of operators to invest in them.[9] Following this reform, Canada's large legacy network operators have started large scale deployments of next generation networks, particularly in Canada's relatively low cost urban centers.[10] Along with reductions in barriers to foreign investment in Canadian telecom operators, CRTC's course reversal with respect to wholesale access to next generation fiber access networks appears to have also helped attract some international investors to the Canadian market.[11]

The analysis offered in this paper focuses on investment decisions made prior to these changes and it is not yet clear if increases in FTTP capital expenditures pursuant to the CRTC policy shift will be sustainable. Nevertheless, the positive investment response in Canada to the adoption of wholesale access obligations on fiber access networks stands in sharp contrast to theoretical and empirical literature suggesting a negative link between access regulation and network investments. In the Canadian case, by offering operators a more than reasonable rate of return if they were to invest in higher speed connections, the policy shift appears to have actually reduced the risk and enhanced the "first mover advantage" in doing so. This experience has obvious policy implications for the U.S. and elsewhere where regulatory forbearance from essential facilities obligations/wholesale access does not appear to be very effective in achieving its objective of promoting FTTP investments.

Although current U.S. FTTP penetration rates are higher than those of Canada (around 11% versus 8% respectively), US rates are around half of the OECD average of 20% (Fig. 1).[12] Given large U.S. operators such as Verizon Communications have essentially halted their FTTP deployments in the past few years in favor of increasing capital intensity into mobile data services,[13] slow, incremental, and highly localized growth in FTTP access appears persistent (Nevo et al., 2016; Wilson, 2017).[14] Without innovative public sector initiatives by municipal, regional, and national governments that help align private and social returns to technological change, operators' incentives to invest in new and decommission old broadband technologies can be very limited.[15]

Previous research on broadband infrastructure development has primarily analyzed the impact of public policy on telecom investment inputs and broadband outcomes such as penetration rates of particular technologies, levels and allocation of investments, prices, and broadband service quality. There has however been little attention paid to strategic choices of operators to meet rapidly growing demand for faster, more symmetric, and reliable Internet connectivity. This paper takes a step in this direction by examining the

[9] While extending wholesale access to FTTP, the CRTC retained the so-called "Phase II" costing methodology preferred by dominant DSL operators (versus retail minus as suggested by cable providers or the Equivalence of Inputs (EoI) approach more commonly used in Europe and proposed by resellers in the Canadian case). Maintaining this costing approach appears to have alleviated concerns by large institutional investors in Canada's incumbent telecom operators about the negative impact of the regulations on relatively attractive dividends they earn from their large positions in these operators. See RBC (2015). The CRTC has not yet approved the wholesale rates, but submissions by incumbents to the CRTC suggest they are expecting a 40% mark up over costs for next generation access (versus around 15%–30% on existing legacy FTTN plus copper last mile services).

[10] Bell Gigabit Fibe internet service launched in Ontario, Quebec, CBC News, August 5, 2015. Available at: http://www.cbc.ca/news/technology/bell-gigabit-fibe-internet-service-launched-in-ontario-quebec-1.3187499 Rogers announces Ignite Gigabit internet, 4 K sports broadcasts, CBC News, Oct 5, 2015. Available at: http://www.cbc.ca/news/business/rogers-internet-1.3256745 Telus boosts Vancouver's internet network with $1B upgrade, CBC News, Oct 2, 2015. Available at: http://www.cbc.ca/news/canada/british-columbia/telus-upgrade-vancouver-1.3254403.

[11] MTS strikes $465-million deal to sell Allstream unit to Zayo Group of U.S. The Globe and Mail, Nov 25, 2015. Available at: http://www.theglobeandmail.com/report-on-business/manitoba-telecom-strikes-465-million-deal-to-sell-allstream-to-us-group/article27436124/.

[12] Verizon's earlier FTTP deployments in the U.S. explain the fact that U.S. FTTP penetration is higher than Canada's. Much like AT&T in the U.S., in the late 2000s Canadian operators Bell and Telus instead chose to pursue a less capital intensive fiber-to-the-node (FTTN)/last mile copper strategy to developing their networks.

[13] See: http://arstechnica.com/business/2015/01/verizon-nears-the-end-of-fios-builds/.

[14] Investments by non-incumbents such as Google Fiber also do not appear to have slowed in the U.S. See https://arstechnica.com/information-technology/2016/10/google-fiber-laying-off-9-of-staff-will-pause-plans-for-10-cities/.

[15] In contrast to Canada, in the U.S. FTTP investment incentives appear to have declined over the past few years as large fixed network operators Verizon and AT&T have adopted an "all in" wireless investment strategy, while cable operators have been investing in media assets, other "verticals" and horizontal consolidation of their underperforming rivals (e.g. TWC/Charter/Spectrum group transactions).

development of fixed broadband networks through the lens of key strategic choices made by large incumbent operators in the United States and Canada since the financial crisis of the late 2000s.[16] The comparative experience with the development of broadband infrastructure in the two countries offers a unique window into broader international debates about strategy and policy in the transition to next generation networks.

The next section analyzes the impact of competition between duopoly operators of the legacy cable and telephone (DSL) networks that dominate local and regional markets, using broadband speed measurements to assess the service quality they deliver to their customers.[17] The evolution of measured connectivity speeds on legacy networks provides an empirical basis for understanding the competitive context of strategic choices by dominant operators, choices that ultimately determine the pace of progress from sunset to sunrise networks. We then evaluate whether and how financial, organizational, and other relevant strategic choices of dominant operators may explain observed network outcomes across firms and in aggregate terms. The objective of the research is to better understand the importance of strategic choices made by dominant operators in shaping the evolution of broadband connectivity, and determining when public policies and business strategies that promote fixed cost sharing and reduce duplication are required for channeling capital expenditures to next generation networks that can scale to meet rapidly growing consumer demand for more symmetric and reliable broadband connectivity.

2. Infrastructure competition, investment, and efficiency

In the first stages of the development of Internet connectivity in the 1990s, federal policymakers in both the U.S. and Canada established unbundling and interconnection obligations for operators of network facilities they considered essential for promoting access and competition in the provision of voice and data services. While initially successful in enabling some entry into low speed access markets, these regulatory obligations did not prove to be effective in either promoting service-based competition or motivating incumbent copper network operators to upgrade their networks for delivering higher speed services in the late 1990s and early 2000s (e.g. by deploying ADSL2+ services). In contrast to various other high income economies where DSL remained the dominant technology, in Canada and the U.S. rapid growth in capital flows to the sector encouraged operators of cable TV networks to make significant investments in extending broadband connectivity at increasingly higher speed than copper/DSL incumbents (Hausman, Sidak, & Singer, 2001; Lenain & Paltridge, 2003; Cambini & Jiang, 2009).

Infrastructure competition is understood to offer an efficient business model and is favored as a public policy where there are similarities in network infrastructure endowments (i.e. nationwide cable TV assets existing in parallel to nationwide telephone networks, as was the case in the U.S. and Canada, but not common in most OECD countries). It offers an alternative to unbundling policies that failed to promote capital expenditures in broadband by incumbent copper monopolies, and is part of the shared history regarding what worked in accelerating broadband deployment at the early stages of Internet development in the U.S. and Canada. This history continues to cast a long shadow over contemporary debates about policies and strategies required for promoting the pace of technological change from legacy DSL and cable connections to fiber access networks.

One important consequence of the relatively unique path of network development in the two countries is that today the U.S. and Canada have some of the highest rates of cable broadband penetration in advanced economies. DOCSIS cable technologies can be configured to deliver higher quality/speed services than DSL, which should create some incentives for legacy telecom operators to bring fiber closer to consumers and upgrade legacy assets in order to remain competitive.[18] Deployment of fiber-to-the-node (FTTN) plus VDSL networks offers a short term solution to provide higher speeds over copper networks at a lower cost than full blown FTTP deployments and allows for continued extraction of FCFs on legacy copper assets whose fixed costs were amortized a long time ago.

Over time however, incremental investments in capacity upgrades of legacy DSL platforms can become increasingly expensive, reducing incentives of operators to provision sufficient capacity in order to meet their contractual obligations to their customers in terms of service quality. This is one reason why studies by various regulators have consistently shown that operators of slower, less scalable, DSL-based services are less likely to deliver the service quality level they advertise, as compared to the providers of cable or FTTP based services (CRTC, 2016; European Commission, 2014; FCC, 2015; Rajabiun & Middleton, 2015c). Operators of existing higher speed cable broadband networks can respond to the strategic imperative of legacy DSL operators who oversell their technological capabilities by investing in more capacity. However, accelerating these investments to gain a larger market share will also divert resources away from capital expenditures on other ventures and away from dividends to investors.

[16] It is important to note that there is a wide range of factors that may explain firm level network development patterns studied in this article and those we analyze should not be considered exhaustive. Mapping combinations and permutations of key strategic choices by operators and what drives them represents an avenue for future research.

[17] While there are various technologies available to make DSL loops faster in the downstream direction over short distances (e.g. G.Fast), long loop DSL cannot even now accommodate broadband subscriber expectations (e.g., 2 or more simultaneous full motion video streams). On shorter loops, even with such upgrades legacy copper-based platforms face significant challenges delivering upload speeds that enable seamless user interaction with the cloud and their service quality tends to be highly variable (i.e. "burstable"). In addition to users of more advanced applications that require fast and symmetric connectivity, faster upload speeds available on fiber are an increasingly important concern for all users trying to protect their information by backing it up in the cloud. See http://www.cio.com/article/3197371/broadband/goodbye-cable-hello-gigabit-broadband.html.

[18] DOCSIS upgrade opportunities tend to have lower costs relative to DSL, which creates some incentives for cable operators to increase bit rates faster than their DSL rivals in order to expand their market share while charging a premium for their higher speed services (see analysis of the evolution of speeds across operators in North America below). Fiber is perceived as overdelivering bit rates that most people might enjoy, but for which many of them may not be willing to pay a substantive margin over service quality levels that are available on DSL and cable.

These considerations suggest infrastructure competition might be an efficient organizational arrangement for promoting investment in existing networks. However, business strategies, corporate cultures and policy strategies that support infrastructure competition also create an incentive structure in the market that can inhibit the creative destruction that drives the transition from sunset to sunrise platforms. The magnitude of these disincentives can vary across particular markets and depends on a wide range of factors, a detailed discussion of which is beyond the scope of this paper. For example, in places where copper/DSL infrastructure is particularly old or has not been upgraded to FTTN/VDSL, incentives to decommission the old and deploy FTTP tend to be stronger (e.g. Verizon in North East U.S., Bell Aliant in Atlantic Canada). On the other hand, in places where cable operators have invested heavily in upgrading their networks (DOCSIS 3.0, 3.1), the expected take up rate for FTTP might be very low unless the potential FTTP operator would be willing to engage in a price war with the cable company (Skiti, 2016).

Historical emphasis by operators and policymakers in the U.S. and Canada on the efficacy of infrastructure competition, rather than service-based competition, partly reflects successes of the past in extending and improving broadband access. It is not clear if replicating policies and strategies that were successful in the past will be efficient in the future however. This is because infrastructure competition does not appear to represent a feasible, or even desirable, strategy in channelling private sector capital expenditures into emerging platforms. The experience in the U.S. and Canada with respect to FTTP deployment over the past few years lends support to this hypothesis. Infrastructure competition has promoted investments in upgrading legacy DSL and cable platforms. Having committed to irreversible capital expenditures to make incremental upgrades in response to competition from the other legacy infrastructure operator, it has become increasingly less attractive for individual incumbents to forgo FCF associated with them and to deploy next generation fiber access networks outside of a small number of urban centers.

The experience in the U.S. and Canada also illustrates the potential for infrastructure competitors to overinvest in legacy assets they control in order to meet growing demand for connectivity. As operators in both North America and Europe like to remind policymakers, telecom investment levels in the U.S. and Canada have in fact been consistently higher than the average of other high income countries (Bell, 2015; Orange, 2015). But despite relatively higher than average levels of capital inputs in North America, the broadband connectivity speeds experienced by customers in the U.S. and Canada are just about the global average. Service quality gaps with leading countries in Europe and East Asia have been in fact widening over the past few years (Fig. 2). This suggests that while relatively more capital inputs were going into the U.S. and Canadian networks, the operators of legacy DSL and cable networks that dominate broadband markets in the two countries were not efficiently translating these inputs into network capacity enhancements and high-speed services consumers value.

This hypothesis is consistent with empirical research showing that aggregate capital expenditure levels in EU member states are not necessarily associated with higher quality networks or higher pace of creative destruction towards next generation network technologies (Rajabiun & Middleton, 2015b). While more disaggregated data on capital expenditure levels and patterns of operators would be needed to explore this issue further, "the relevant point here is whether or not operators are able to translate their capital expenditures into real improvements in the quality of the network" (European Parliament, 2016, p. 27). This question is not only important for policymakers mandated to create conditions for the efficient delivery of social and business infrastructure such as broadband Internet connectivity, but also for telecom investors looking for undervalued assets or targets for deploying advanced infrastructure in particular segments of the broadband ecosystem.

3. Broadband network infrastructure outcomes

From an economic perspective, the ability of firms to translate capital inputs into network outcomes can be measured using indicators of quality and price of services. In order to better understand comparative differences in the evolution of infrastructure competition in the U.S. and Canada, we utilize broadband speed measurements collected by the M-Lab testbed.[19] As noted, advertised and actual speeds can vary significantly across operators of sunset and sunrise platforms as operators of slower legacy platforms have stronger incentives to overstate the actual service quality they can deliver relative to capacity they have provisioned for particular customers.[20] The M-Lab platform enables users to test their connections and collect a large set of metrics regarding their connection quality and potential variables that might explain it (Web 100 indicators).[21] Among these variables, we focus only on download speeds, the key measure for economic value operators advertise and try to deliver to their broadband customers. Nevertheless, it is important to note that download speeds are not the only relevant indicators of network outcomes. Enhanced symmetry and reliability represent some of the key reasons for increasing the pace of progress from legacy to next generation networks (e.g. upload speeds, latency, availability of service quality guarantees, scalability, etc.).

We take a two-step approach to exploring data underlying country-level FTTP penetration and evolution of connectivity speeds. Figs. 3–5 document bandwidth tests collected by M-Lab's distributed testing infrastructure over a one-year period between July 2015 and July 2016 for the U.S., Canada, as well as Sweden for comparison (using RIPE Network Coordination Centre's Observed Bandwidth

[19] https://www.measurementlab.net/.

[20] In addition to access technology and provisioning practices of operators, speed measurements reflect the demand/willingness of customers to pay for service packages advertising particular speeds at various price points. Even when higher speeds are advertised and consumers are willing to pay a premium to move up to a higher speed tier, these advertised speeds are not necessarily delivered. For example, evidence compiled by the State of New York in a lawsuit against one of the biggest cable broadband providers in the U.S. suggests actual speeds of premium plans (with 100–300 Mbps in advertised speeds) were up to 70% slower than those it had promised customers. See Supreme Court of the State of New York, case no. 450,318/2017; available at: https://ag.ny.gov/sites/default/files/summons_and_complaint.pdf.

[21] http://www.web100.org/. https://github.com/ndt-project/ndt/wiki/NDTProtocol#Appendix_A._web100_variables.

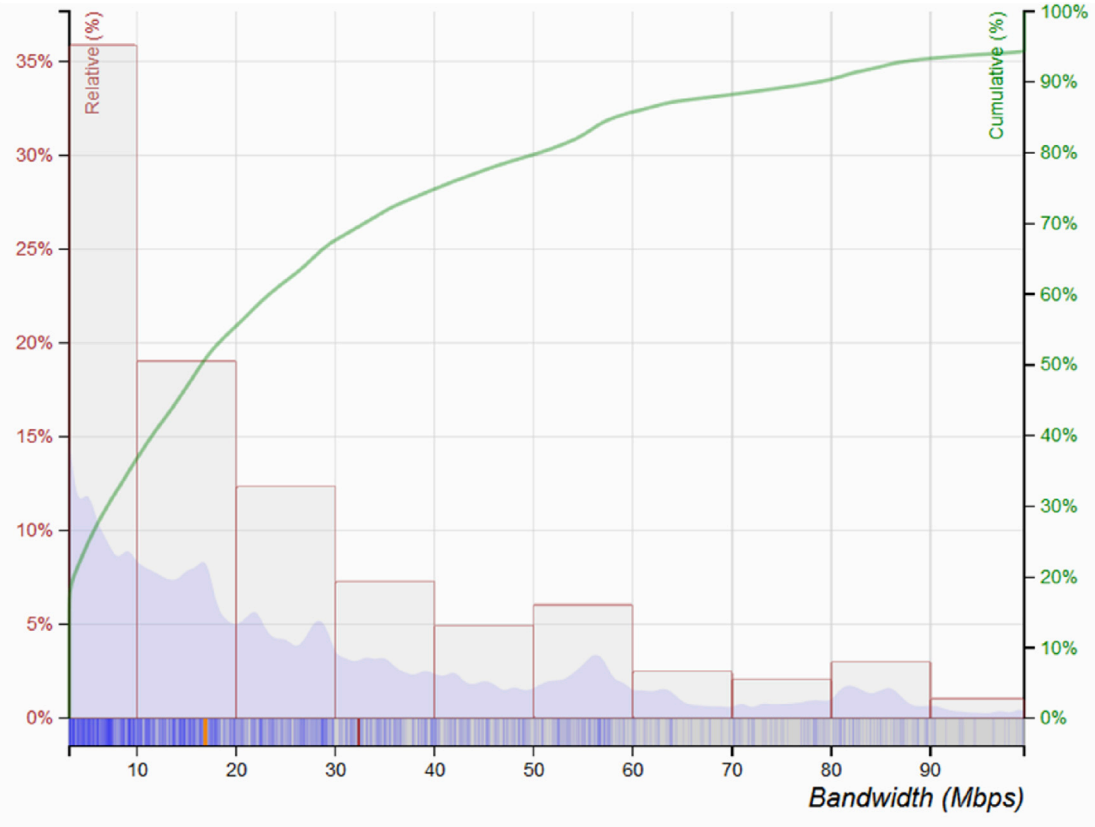

Fig. 3. Distribution of Connection Speeds in the U.S. (2015–2016) Source: RIPEstat, n = 99,999.

Capacity Widget for characterizing M-Lab data).[22] Since Sweden is much further along in transitioning to FTTP than the first two (over 50% FTTP penetration), it offers a useful illustration for interpreting comparative differences in the structure of connectivity generated by infrastructure competition in U.S. and Canadian markets.[23] We then present firm-level indicators of network outcomes in the two countries and evaluate how they have co-evolved in an environment of infrastructure competition.

These visualizations highlight substantive differences in the distribution of network capacity in the three countries by capturing a combination of factors, including the technological landscape and common service tiers. The distribution of measured broadband speeds is consistent with differences in aggregated FTTP deployment and penetration rates. For example, in Canada where FTTP diffusion has been negligible, even in urban centers where more than 80% of the population reside, around 95% of connections had speeds lower than 50 Mbps, which is consistent with the 5% FTTP penetration rate from 2015 data.[24] For the U.S., 80% of tests were below 50 Mbps, which is also consistent with its FTTP penetration rate.[25] Higher capacity connections are clearly more prevalent in Sweden, a country where a combination of public and private sector initiatives have been relatively successful in promoting FTTP deployments.

What is particularly interesting from the comparisons is the distinctive nature of the Canadian results on the lower speed tiers (left hand side of the figures, below 20 Mbps). In addition to having the highest proportion of low speed connections, the evident peaks around 5, 10, and 15 Mbps reveal heavy reliance on "speed tiering" by legacy platform operators in Canada. This approach allows these operators to manage scarce network capacity on legacy networks that are hard to scale and implement "smart pricing" strategies that

[22] https://stat.ripe.net/widget/bandwidth#w.resource.

[23] Relatively high FTTP penetration rates in Sweden have been primarily driven by municipal leadership in channeling private investments into open access fiber networks, on top of which multiple operators are encouraged to compete. Compared to Japan and Korea where the central government took the lead in the 2000s to adopt policies that channel private capital expenditures to FTTP deployments, the Swedish experience therefore represents a more decentralized model where collective action at the local level has helped overcome market failures in the transition from legacy copper to next generation fiber platforms. It therefore represents a useful benchmark for federalist countries such as Canada and the U.S. where lower levels of government are ultimately responsible for delivering social and business infrastructure such as broadband Internet access (see Rajabiun & Middleton, 2013).

[24] See OECD Broadband Statistics, Table 1.10, Percentage of Fiber Connections in Total Broadband Subscriptions (June 2015).

[25] In theory, both cable DOCSIS 3.0 and upgraded DSL over short distances (e.g. G.Fast) may be able to deliver downstream speeds higher than 50 Mbps in the absence of congestion. Despite this headline "up to x Mbps" speed as advertised in retail contracts, in practice speeds offered by most DSL and cable operators in U.S. and Canada fall well below those of incumbent or entrant FTTP providers. As detailed further below, there are exceptions to this as some cable operators have invested relatively more in capacity enhancements to expand their lead over FTTN/DSL operators than others (e.g. Rogers, Cogeco in Canada v. TWC in U.S. or Shaw in Canada).

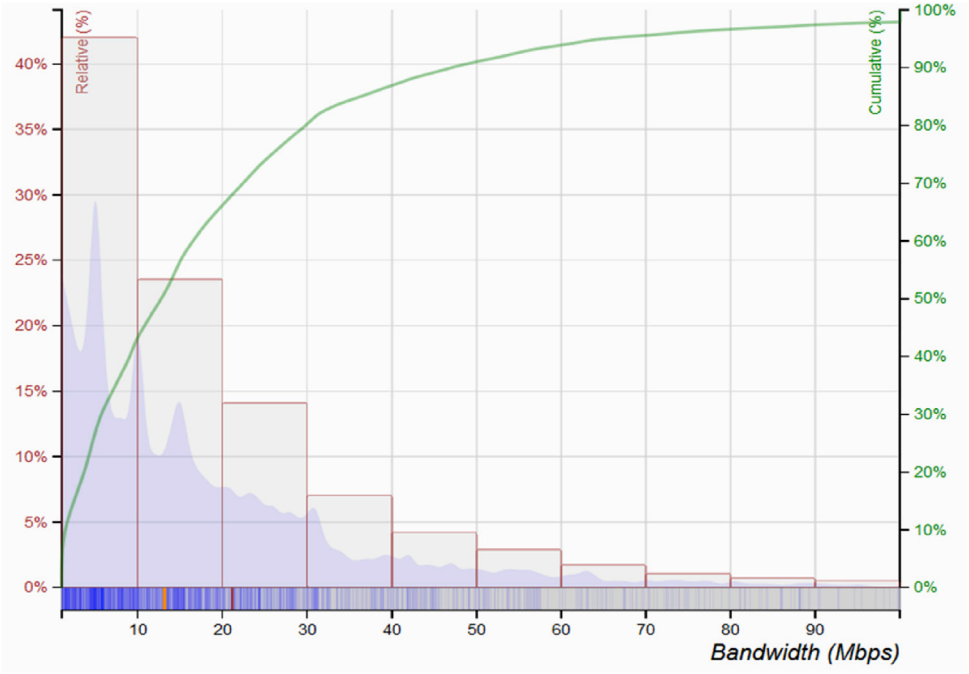

Fig. 4. Distribution of Connection Speeds in Canada (2015–2016) Source: RIPEstat, n = 99,999.

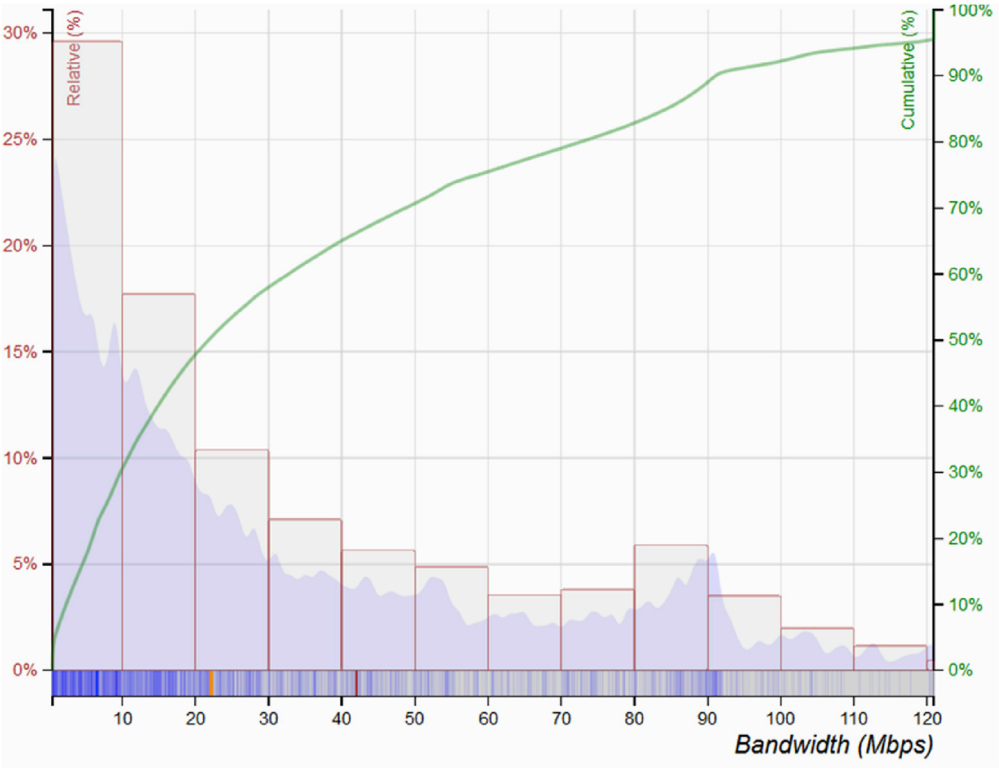

Fig. 5. Distribution of Connection Speeds in Sweden (2015–2016) Source: RIPEstat, n = 54,845.

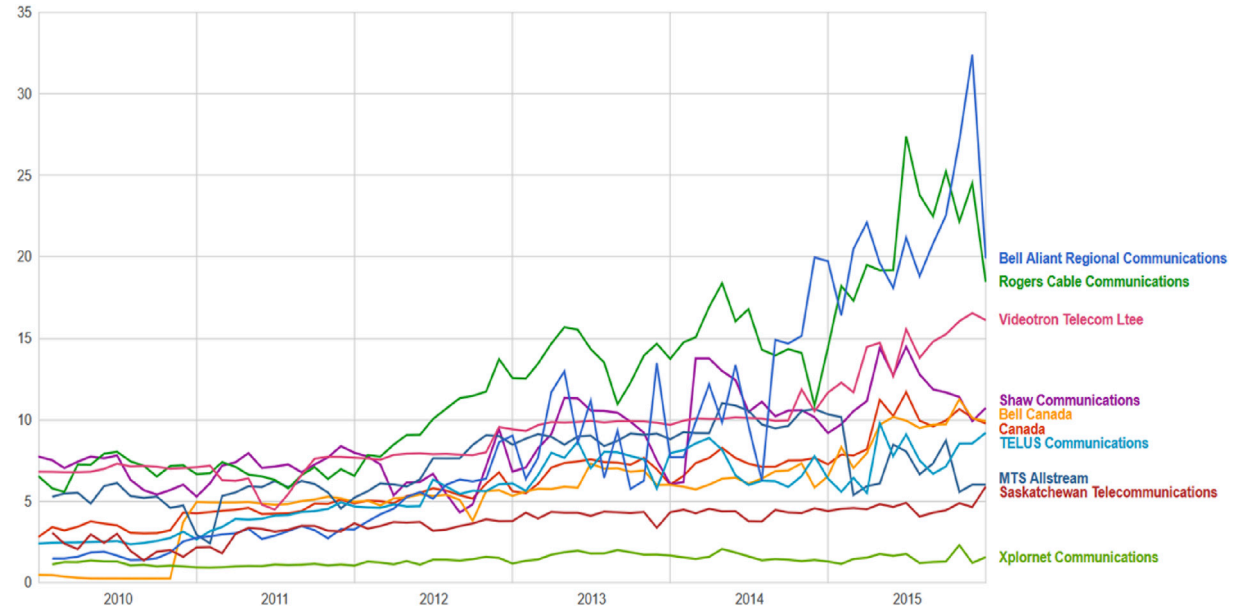

Fig. 6. Median download speeds by operators in Canada. Source: M-Lab/Google public data explorer.

enable them to extract more consumer surplus in a market where end users have relatively limited options. Measured speed tiers in the U.S. are less pronounced and higher than in Canada, centered around 20 and 30 Mbps for services based on legacy platforms, and around 55 Mbps levels for next generation connectivity where it is available. Canadian consumers with high demand for network resources simply do not have the options that are available in certain U.S. cities and more generally in Sweden, forcing them to stay on legacy infrastructure. Relatively limited access to next generation FTTP platforms in Canada and extensive service quality differentiation appears to have a relatively stronger negative externality on service quality that is available to others on the lower speed side of the market. For example, the proportion of connections with speeds below 10 Mbps is substantially higher in Canada than either the U.S. or Sweden (approximately 50% versus 40% and 30% respectively).

Although access technologies and average speed levels in the U.S. and Canada are fairly similar, there are clear differences in the distribution of network outcomes in the two countries. To better understand how performance differences among operators relying on different technologies for delivering broadband connectivity shape these outcomes, Figs. 6 and 7 illustrate the evolution of median download speeds by a selection of large operators, as well as some smaller FTTP and satellite-based providers for comparison.[26]

Differences in levels and patterns of network development across firms in the two countries offer a number of insights that are relevant for understanding distinctive implications of infrastructure competition in two jurisdictions with relatively similar technological endowments (i.e. near universal legacy copper and cable). On the top of the figures, Bell Aliant and Google Fiber are examples of smaller regional incumbents and entrants that have deployed FTTP networks in particular communities; representing two distinct paths in the transition from legacy to next generation networks. DSL-based providers operating in more rural areas and satellite-based providers deliver some of the lowest speeds, explaining growing concerns about the urban-rural digital divide in both countries over the past few years where access to faster cable networks can be limited. Between these extremes are the larger DSL and cable based operators on which most users in these markets rely for connectivity.

In Canada, median download speeds delivered by cable broadband providers (e.g. Rogers, Videotron, Cogeco, operating in Ontario and Quebec) have been consistently higher than those of DSL/FTTN based providers (Bell, Telus, SaskTel, MTS). The exception to this is the dominant cable network operator in western Canada (Shaw), which does not appear to have improved network speeds as fast as its counterparts in central and eastern regions of the country. This highlights the relevance of operators' strategic choices about their capacity enhancement rates relative to their competitors in shaping connectivity at regional and local levels.[27] In contrast to Canada where the largest cable provider, Rogers, appears to have made the decision to substantially expand its lead over its largest DSL-based competitor Bell, only a number of smaller regional cable providers in the U.S. adopted a similar competitive strategy (e.g. Wave, Cablevision, RCN). While still relatively faster than some of their DSL-based competitors, large cable companies in the U.S. such as

[26] It is important to note that, particularly in the U.S., mergers and acquisition activity have altered names and corporate structures of some of the operators, which makes it challenging to explicitly connect broadband network outcome measurements with other firm-level indicators that might help explain these outcomes. There are also some missing data points in the Google Public Explorer interface with the M-Lab test statistics database we use here to capture how infrastructure competition has shaped firm level network outcomes (e.g. Verizon Communications in the U.S.).

[27] Note that competition in Canada is regionally based, with different pairs of cable companies and incumbent telcos competing in different markets.

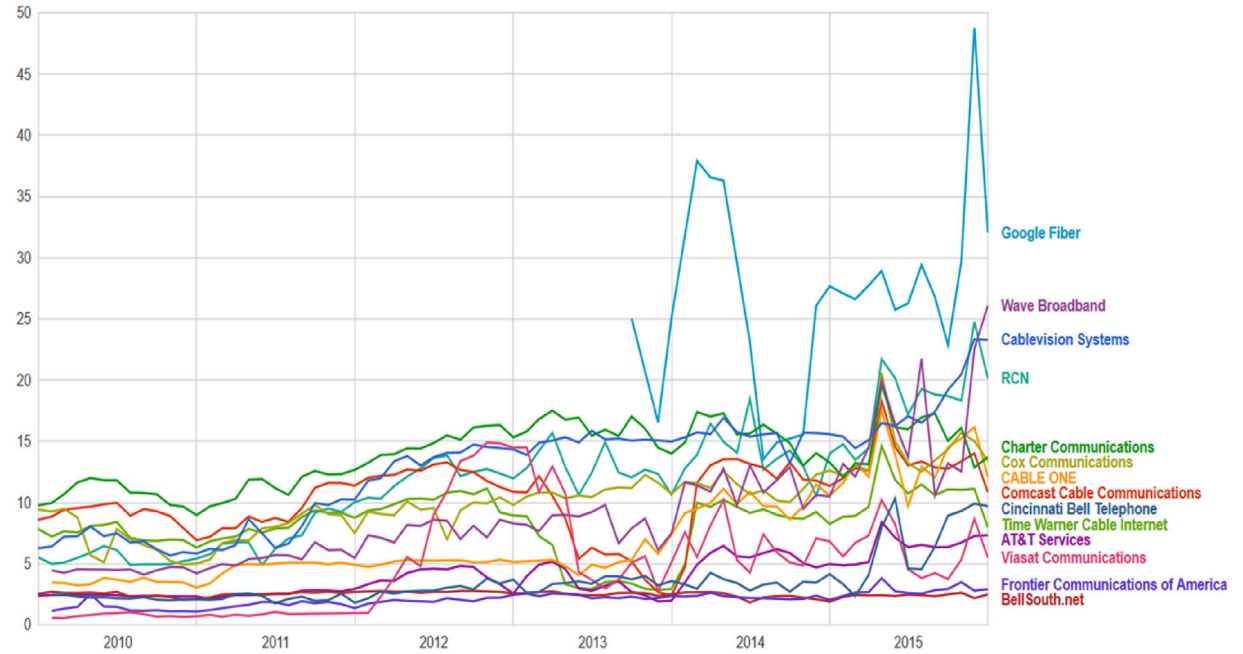

Fig. 7. Median download speeds by operator in the U.S. Source: M-Lab/Google public data explorer.

Comcast and Time Warner started the period with relatively similar speeds but started to fall substantially behind their Canadian counterparts such as Rogers and Videotron by the end.

By 2016 median download speeds delivered by large cable operators in the U.S. were around 10–15 Mbps, about one half of those delivered by higher performing smaller U.S. and large Canadian cable providers (with speeds in the 20–25 Mbps range). Importantly, by the end of the period median speeds delivered by large U.S. cable operators were about the same as those delivered by larger DSL/FTTN operators in Canada. These observations highlight the importance of legacy network operators' strategic investment choices for the quality of connectivity they deliver to their customers, rather than their technological endowments per se. At least in central Canada where most of the population resides, infrastructure competition appears to have been more successful than in the U.S. for motivating legacy operators to invest in network capacity enhancement.

Given the relatively large and diverse nature of the U.S. market, the picture with respect to technological and geographical differentiation in capacity and service quality development is not as clear cut as in Canada. Variations in broadband speeds across legacy network operators, some of which have been integrated into others due to horizontal merger and acquisition activity in this period, further highlight the importance of strategic choices by managers and investors in these entities to leverage their networks in order to derive consumer and firm value. The firm level perspectives noted above also hide significant diversity and differentiation in service areas of large operators. For example, within relatively low cost/high revenue urban areas of the U.S. where infrastructure competition has been more intensive some incumbent telephone companies have decided to deploy FTTP. In order to better understand the impact of infrastructure competition in the relatively complex and differentiated U.S. market, Table 1 characterizes median download speeds as of July 2016 for the four largest incumbents, Comcast, TWC (acquired by Charter in 2016), Verizon, and AT&T, in a number of relatively low cost/high return urban centers.

In these settings, the threat of accelerated investments by the other legacy network incumbent, and potential of entry from non-incumbent service providers is likely to be at its highest. The sharp contrast between decisions by incumbent copper network operators, specifically Verizon's decision to deploy FTTP in certain urban areas and that of AT&T to "sweat the copper" with DSL/FTTN upgrades is evident in the data. Where Verizon has taken the initiative to decommission more of its legacy platforms and deploy FTTP, its offerings have become substantially more competitive to cable incumbents. In these metro markets (e.g. NY, DC, Southern California),

Table 1
Network performance of largest operators in selected high value urban markets.

	New York	DC	Chicago	Southern California	Miami	Atlanta
Comcast	35	46	26	30	27	10
Verizon	60	62	X	35	26	6
AT&T	X	X	17	18	18	2
TWC	48	15	12	35	X	5

Source: M-Lab, US Internet Observatory. July 2016, median download speeds in Mbps; X indicates that an operator does not serve a market or comparable data is not available.

cable companies have responded by enhancing their capacity relative to those markets where incumbent DSL operators have had limited incentives to deploy FTTP access networks (e.g. Chicago, Miami, Atlanta). The fact that higher speed connections are substantially more prevalent in the U.S. than in Canada (Figs. 3 and 4 above) captures the fact that in a small number of large cities in the U.S. infrastructure competition has helped promote technological change from legacy to next generation FTTP platforms. This is not the case in Canada where FTTP deployment incentives remained low even in relatively low cost/high value urban markets such as Toronto and Vancouver where operators of legacy cable and DSL platforms have invested relatively heavily in upgrading their capacity to deliver higher speeds.[28]

4. Strategic choice

Beyond the competitive options available to dominant providers in terms of capacity enhancement rates and technological choices between upgrading the old and building the new (i.e. DSL, G.Fast, DOCSIS 3.1 versus FTTP), a wide range of other firm-level strategic considerations might be relevant for explaining network outcomes outlined in the previous sections. While it is beyond the scope of this article to provide an exhaustive list of relevant factors shaping these strategies and there are a lot of unknowns about why particular operators make particular decisions, the experience in Canada and the U.S. suggests the relevance of a number of key choices by dominant network operators in explaining growing unevenness of connectivity within the two countries. In general, regional duopolies of network operators with substantive free cash flows (FCFs) from irreversible capital expenditures on legacy DSL and cable networks have the option to return it to investors in the form of dividends, reinvest in their networks, or purchase other types of cash flow generating assets.

4.1. Vertical strategies

In addition to reinvesting in their fixed network capacity, since the late 2000s various U.S. and Canadian incumbents have become more vertically integrated by purchasing a variety of non-telecom assets such as media, entertainment and sports, data services, home security, etc. (Canadian Media Concentration Research Project, 2016). Importantly, large copper network incumbents have also invested heavily in developing 4G LTE mobile networks. Since mobile network development tends to be less capital intensive than fiber deployment, the wireless strategy of most large DSL incumbents in North America partly explains growing gaps between fixed speeds they deliver compared to those of cable providers.[29] Large cable companies in the U.S. have been reluctant to enter the mobile market and have remained more focused on delivering multiple services on their IP-enabled fixed networks.[30] Rogers, which was the initial leader in deploying fixed and mobile broadband in Canada, represents an example of a cable company that has had little option but to compete with regional incumbent telecoms Bell and Telus in both fixed and mobile markets. Despite this, Rogers has shown relatively strong propensity to invest in its networks in order to substantially outperform Bell's DSL/FTTN based services. The decision by Verizon in the U.S. not to continue its FTTP deployments and instead focus its capital intensification efforts in the less capital intensive/faster growth mobile market highlights how excessive vertical integration can lead to a rationing of scarce resources needed for the transition to both fixed and mobile next generation networks.[31] Although performance of smaller, less vertically integrated DSL and cable operators varies, a number of smaller more specialized cable and FTTP providers have been able to scale their networks relatively faster than their larger vertically integrated counterparts.[32]

4.2. Horizontal alliances and acquisitions

Although network deployment is fundamentally a local enterprise, there are scale economies in marketing and operations. The potential for reducing costs can create strong incentives for horizontal agglomeration, as exemplified in the consolidation of larger public cable companies in the U.S. over the past few years into larger groups with a broader geographic reach. In Canada, cable operators continue to be closely held by their founding families (e.g. Rogers, Shaw) and the scope for their acquisition has been limited. Bell and Telus however have a wide ranging alliance in which one party utilizes the network infrastructure of the other party in regions where

[28] This appears to have changed more recently subsequent to the CRTC decision to reverse course and extend wholesale access obligations to next generation fiber access networks at an attractive regulated price that aims to incentivize operators to invest in them. Various incumbents have announced they will start to deploy next generation FTTP networks in Canada's large urban centers such as Toronto and Vancouver. See supra note 10. The extent to which these announcements will materialize to deployment and FTTP penetration is not yet clear as doing so raises concerns by investors about growing capital intensity and reduced dividends.

[29] The theoretical potential for "small cell" 5G networks to offer connections with service quality comparable to fixed FTTP may partly explain the apparent preference of some incumbents to stretch the useful life of DSL and cable broadband instead of directing capital expenditures to the development of fiber plants.

[30] This appears to be changing in 2017, but was true for the period being analyzed in this paper. See: https://arstechnica.com/information-technology/2017/01/comcast-mobile-phone-service-coming-in-2017-with-wirelesscable-bundles/; http://www.analysysmason.com/Research/Content/Comments/Verizon-Charter-USA-Jan2017-RDCS0-RDNS0/.

[31] See: http://arstechnica.com/business/2015/01/verizon-nears-the-end-of-fios-builds/.

[32] Vertical integration strategies of large operators into non-core assets can have strong implications for their risk profile, costs of raising external funds, and the allocation of retained earnings among competing lines of business within the operator. On the other hand, control of media and other over-the-top (OTT) services creates opportunities for bundling, tied selling, and smart pricing strategies that enhance the capacity of operators to monetize fixed network assets. At the margin, the discount rate by which operators value short to medium term cash flows from monetizing legacy assets through vertical integration versus long term growth by making capital expenditures on next generation platforms is likely to be a key driver of their decisions to integrate by investing in non-network assets or remain specialized as network operators.

they are not an incumbent to deliver mobile and business data, but not residential broadband. These types of horizontal alliances can help reduce the potential for inefficient duplication and therefore reduce the costs of deploying next generation networks, casting further doubt on the hypothesis that infrastructure competition is an efficient strategy for accelerating the pace of progress from sunset to sunrise network technologies. While potentially efficiency enhancing in the longer term, such horizonal alliances and mergers would nevertheless create significant competition concerns in the short to medium term in both broadband and vertically related markets controlled by incumbents. Consequently, they are not necessarily feasible or desirable, motivating the search for innovative organizational arrangements, strategic partnerships, and public policy initiatives that aim to promote cooperation and risk sharing in the transition from legacy to next generation networks.

4.3. Dividend strategies

Previous research indicates that pressures from financial markets shaped by investor preferences and reactions of analysts can pose a constraint on strategies available to managers of network operators in deploying new technologies (Benner & Ranganathan, 2013). Increased investments in networks may not fit the requirements of investors used to relatively attractive dividend payouts available on legacy platforms. In the longer term however, low investment in capacity growth degrades service quality consumers receive, resulting in increasing churn and loss of market share. The fact that U.S. and Canada have some of the highest cable broadband market shares in the world highlights the relevance of this problem for legacy DSL/FTTN operators, as does financial market concerns about increased capital intensity of Verizon's business as a consequence of the lead it took in the mid-2000s to accelerate its FTTP deployments. The resistance by Canadian operators' large institutional investors to strategies and policies that accelerate FTTP deployments, and therefore can reduce large dividends to which the investors are accustomed, are also well documented (RBC, 2015).

Table 2 provides a firm-level perspective on how operators in the two countries have balanced the short and long term financial imperatives that influence their choices about network capacity enhancements detailed in previous sections. The proportion of free cash flows Canadian operators return to their investors as dividends is substantially higher than in the U.S. with respect to most copper and cable network operators. The exceptions to this are Cogeco and Quebecor (Videotron's parent company), two of the smaller Canadian cable operators that have experienced relatively strong growth in measured speeds and are today leading many of their counterparts in both Canada and the U.S. in terms of service quality they deliver to their customers. In contrast, Shaw, the cable company with the slowest increase in median speeds it delivers relative to its regional DSL competitor (Telus), returns almost all of its FCF as dividends to its owners. Reasons for the relatively low dividends from Comcast and Time Warner (acquired by Charter) are not obvious, but are likely to reflect firm specific strategies and competitive conditions.

4.4. Marketing strategies

Previous research on FTTP deployment projects suggests the critical factor in their commercial success is their capacity to maximize the number of subscribers, an outcome facilitated by aggregation of demand (Domingo, Van der Wee, Verbrugge, & Oliver, 2014; Felten and Swain, 2009). One marketing strategy that limits the capacity of operators to sell next generation FTTP services is the fact some of them have been offering services that are based on fiber-to-the-node (FTTN) plus last mile legacy DSL/cable links to end user premises using marketing terms such as "Fibe" and "Optik". While these marketing terms suggest that customers indeed have a preference for the faster and symmetric speeds that fiber can deliver, having used them in the past to sell services based on last mile legacy copper/DSL lines limits the ability of incumbents to go back to customers and convince them to pay a higher price for an actual FTTP connection to their homes or businesses. Although this marketing strategy may have had some short-term benefits for legacy DSL operators by enabling them to better compete with faster/higher quality services cable operators can deliver, it will limit their ability to aggregate demand in the future. Relatively high levels of past investment by cable companies in capacity to enhance their lead in terms of service quality also reduces the expected subscription rates for new FTTP services. Some cable operators can therefore have strategic incentives to "over-invest" in upgrading their capacity relative to DSL/FTTN incumbents in order to deter the possibility of FTTP deployments (Skiti, 2016).

Table 2
Telecom Financial Performance and Dividend Strategies: Canadian v. U.S. incumbents.

Operator	Price-earnings ratio/multiple	Dividend yield %	Dividend as % of free cash flows
BCE	17	4.8	87
Telus	19	3.8	83
Manitoba Tel.	17	4.5	68
AT&T	14	5.5	73
Verizon	14	4.6	62
Rogers	15	4.2	87
Shaw	14	4.4	97
Cogeco	13	2	25
Quebecor	24	.5	9
Comcast	19	1.7	29
Time Warner	25	1.6	40

Source: RBC Telecom Scenario Report, RBC Capital Markets. August 19, 2015, Exhibit 12, page 29

5. Summary and implications

As access to broadband Internet connectivity has become essential, a large body of research has evolved to evaluate the impact of public policy and regulation on the development of the physical infrastructure that supports the digital economy. Relatively little attention has been devoted to understanding the diversity of strategic choices by operators that tend to dominate the broadband infrastructure market and whose decisions shape the development of privately provisioned broadband networks. The evolution of broadband connectivity in Canada and the U.S. outlined in the last sections illustrates that strategic choices of dominant operators in response to growth in demand by consumers for higher speed connectivity have not been uniform and have had some impact on the quality of infrastructure they deliver to their customers. Given unified national regulatory regimes in both countries, the evidence highlights the importance of these private sector choices in explaining growing unevenness of broadband infrastructure quality within the two countries.

In the much larger U.S. market, with larger operators, the scope for the development of FTTP networks has been localized, but incentives to deploy them have been relatively higher than in Canada. Decisions by large DSL providers to extend free cash flows from their legacy infrastructure, rather than investing in FTTP, have had distinctive impacts on the incentives of legacy cable providers to increase their speeds in different regions of both countries. Where the incumbent copper operator has accelerated FTTP deployment in the U.S., large cable operators appear to have been incentivized to improve service quality levels they deliver to their customers. Some cable providers appear to have increased network capacity substantially relative to their local DSL competitors, while others appear to have chosen to provision sufficient capacity to just outperform their rivals.

Given that increasing fiber deployment will necessarily imply an increase in the capital intensity of an operator's business and limit its ability to pay dividends, investors used to large short-term returns from copper and cable assets can pose a significant barrier to the ability of individual operators to deploy more fiber. For example, shortly after the CRTC 2015-326 decision in Canada extending wholesale access obligations to FTTP and signals by operators that they will start to accelerate their fiber deployments in certain urban centers, the largest institutional shareholder in Bell Canada Enterprises (Royal Bank) issued a report warning the operators " we see an increased risk of elevated capex intensity … …. Should the telcos enter a phase of elevated capex intensity, we will have to weigh the incremental growth opportunity but negative FCF impact against the lower capex risk profile" (RBC, 2015; p. 1).[33] In the U.S., similar concerns by risk averse investors about increased leverage or reduced dividend levels of incumbents such as Verizon (which have clearly benefited from reduced costs and increased revenues from accelerated FTTP deployment) are likely to restrict their ability to invest in relatively capital intensive fiber access networks in the future (Morningstar, 2016).

Policies and strategies associated with infrastructure competition appear to have been successful in extending broadband access and adoption in the first stages of the development of the Internet in both U.S. and Canada. Over the past few years however, regulatory forbearance from essential facilities obligations and relatively high levels of capital expenditures in the two countries have not led to a substantive increase in the pace of progress in the transition from legacy to next generation networks. Regulatory and public policies that create disincentives for stretching the usable life of legacy infrastructure and stimulate business strategies that invest in next generation networks are likely to be required to reverse these trends.

Wholesale access obligations represent one policy instrument that can be optimized to allow for achieving these objectives simultaneously by differentiating the wholesale markup rate over cost/expected rate of return between legacy and next generation technologies. A low (or negative) expected wholesale margin on legacy platforms is likely to reduce investments in them, while a wholesale regime that offers a more than reasonable rate of return for deploying scalable next generation networks and reselling this capacity to third parties may enhance the "first mover" advantage in doing so. This approach can also reduce the risk of inefficient duplication that can occur if multiple infrastructure competitors were to deploy FTTP. A low wholesale margin on copper and a high one on FTTP was famously and effectively deployed in Japan in the 2000s to support its rapid transition from copper/DSL to FTTP.[34] At the margin, policies that enhance market transparency and enable operators of higher quality/capacity platforms to differentiate themselves from slower legacy networks prone to over-promising what they can deliver to customers may also have a positive impact on incentives to take on the risks of investing in new platforms.[35]

Acknowledgement

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[33] It is relevant to note however that RBC analysts appear to recognize that the CRTC decision to reverse course and extend wholesale access to fiber is not likely to have a negative impact on profitability as the CRTC adopted a pricing model that provides the private sector with an attractive return on their investment in next generation FTTP networks (RBC, 2015, p. 14). Policies and strategies that ameliorate concerns by investors about their impact on dividends or leverage are likely to be required for overcoming disincentives to decommission sunset platforms and deploy new technologies that meet the growing demands of users.

[34] See Minamihashi (2012). While the specific pricing parameters of Canada's new wholesale access regime have not yet been specified by the federal regulator, early evidence suggests that reducing wholesale margins on slower legacy services and offering a large markup on ultra-high speed fiber access networks has enhanced operator incentives to accelerate fiber deployments. See supra note 10.

[35] See Rajabiun and Middleton (2015c). Ex ante minimum speed/quality of service standards in retail contracts (versus/in addition to "up to" maximum "best effort" rates) and ex post penalties for misleading advertising may also have a similar efficiency enhancing impact on the rate of creative destruction as they can reduce the incentives of legacy network operators to sustain "sweating the copper" strategies and increase those of investors in high-capacity fiber platforms. For details of methods used by some incumbents who adopt an under-provisioning/overpromising network planning/marketing strategy see State of New York v. Charter/Spectrum/TWC (2017): https://ag.ny.gov/sites/default/files/summons_and_complaint.pdf.

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