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Lemons on the Edge of the Internet: The Importance of Transparency for Broadband Network Quality

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Abstract: Network performance measurements from OECD countries between 2007 and 2012 document a significant increase in the variability of broadband infrastructure quality, which helps explain growing demand for technologies and policies that counteract information asymmetries between network operators and end users. A cross-country analysis documents the negative association between quality uncertainty and variations in digital infrastructure quality. The analysis suggests public policies and business models that promote market transparency can enhance the efficiency of the broadband access market on the edge of the internet and stimulate incentives for the diffusion of next generation platforms.

Key words: broadband internet, quality uncertainty, market efficiency, technological change.

This article explores the implications of uncertainties in the quality of service end users experience on broadband internet access network infrastructure. The quality of service end users receive on broadband access networks at a particular point in time depends, among other factors, on the level of demand for network resources by other end users in the vicinity. Retail contracts between access providers and end users typically specify the expected quality of service in terms of a maximum link speed, but often also indicate that the actual quality of the service the buyer will achieve is likely to be lower than this theoretical maximum

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(i.e. "up to" xMbps). This approach to contractual design at the retail level incorporates a relatively soft performance target, which provides the seller with some discretion to determine how it allocates scarce network capacity when demand is high and how much it invests in network capacity to meet expected future demand. In practice actual and advertised service quality can vary significantly across time - i.e. late afternoons and evenings versus after midnight (BAUER *et al*., 2012) and applications (i.e. throttling resource intensive applications in high traffic periods) [1]. Retail contracts that specify harder performance targets (e.g. minimum, average, median performance quarantines versus the current maximums/"up to" xMbps) have not yet proven to be a feasible solution to the problem of quality uncertainty in the provision of broadband access services. [2]

This form of incomplete contracting may represent an important problem for the evolution of this key element of digital economy. As detailed long ago by AKERLOF (1970), business and economic history provides a variety of examples in which irreducible uncertainties about quality of currencies, products, and services create perverse incentives in the evolution of market systems, as "dishonest dealings tend to drive honest dealings out of the market" (AKERLOF, 1970, p. 495). Even if there are a large number of buyers of high quality products and sellers willing to meet their demand, the existence of the so-called Lemons Problem can generate markets where low quality goods dominate since providers of high quality goods cannot credibly signal the quality of their products due to the noise from their low quality rivals. A number of recent studies explore the relevance of the Lemons

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[1] A variety of tools are available that enable end users to assess the quality of their connections, how quality evolves over time, and how operators treat particular applications. For an overview of different approaches to broadband speed measurements see BAUER *et al*., (2010). Some content and application providers that require high speed connectivity to serve their customers such as Google/YouTube and Netflix also allow end users to monitor service quality their broadband operators are actually providing in the case of their applications. In addition to general speed measurements and content/application provider specific metrics, specialized tests focus on interference (e.g. blocking, throttling) by some operators on particular forms of traffic flows and communication processes. As an example of such tests focusing on the treatment of peer-to-peer traffic see data from the Glasnost project:http://broadband.mpi-sws.org/transparency/results/; http://netneutralitymap.org/

[2] Policymakers have increasingly recognized this problem by referring to actual versus advertised rates in their future policy targets. See for example:
http://www.broadband.gov/plan/2-goals-for-a-high-performance-america/
http://ec.europa.eu/digital-agenda/; http://www.crtc.gc.ca/eng/archive/2011/2011-291.htm.
Nevertheless, operationalizing "actual" broadband speed remains a challenge as there is little consensus about what type of performance metrics should be employed to monitor the pace of progress in achieving stated policy targets and/or in the application of legal prohibitions against misleading advertising.

Problem in the provision of internet access network platforms, suggesting that specific characteristics of the market accentuate usual concerns about market inefficiency associated with quality uncertainty (SLUIJS *et al.*, 2011; LÓPEZ ZORZANO *et al.*, 2012). Concerns about quality variability have also motivated various governments in advanced economies to deploy large scale network testing projects to benchmark and monitor the quality of Internet connectivity (relative to advertised speeds and/or standards of service required for network intensive applications such as multimedia, cloud computing, IPTV, etc.). [3]

This article contributes to the empirical and policy debates with a cross-country analysis of fixed line broadband performance measurements, as well as a wide range of other factors that potentially impact the quality of Internet connectivity. The next section provides a brief overview of the problem. Then we present and analyze evidence from OECD countries. The conclusion draws inferences for the design of public policy and management strategies of Internet access infrastructure providers.

■ Overview: uncertainty, strategy, and platform quality

While other indicators of network quality might be relevant for particular applications, the speed of Internet connections represents the primary measure of economic value that end users receive from broadband

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[3] For examples of test beds funded by National Regulatory Authorities (NRAs) that employ hardware installed at end users' premises to monitor connection quality see: http://www.samknows.com/broadband/fcc_project; http://www.crtc.gc.ca/eng/pol/pdr-epr7.htm; European Commission (2013). Various NRAs also provide a link to software based tests that allow end users to access a test server on the network and assess their connection quality. It should be noted however that it is not clear how much these efforts improve on available sources of data and the reliability of their results remains in some doubt for a number of reasons: Both hardware and software based testing methodologies employed by NRAs tend to evaluate connection quality by sending generic test packets between end users and a test server (e.g. SamKnows, M-Lab NDT, Ookla/Speedtest). While these tests can have useful information about the technical quality of the connections, they do not necessarily represent a realistic picture of the quality of service end users experience while deploying network intensive content and application services. Consequently, such tests cannot account for dynamic flow control/prioritization policies operators employ to ration scarce network resources in high traffic periods (or when they want to limit end users' ability to deploy particular content and application services for strategic anti-competitive reasons). Furthermore, the results of such tests can be open to manipulation as capable network operators can try to identify popular test servers and over-provision capacity to them in order to achieve better public speed test results, attract customers, or demonstrate to legal authorities that the gap between what is promised and delivered is not sufficiently large to justify a remedy.

infrastructure providers (BAUER *et al*., 2010). As noted, quality of service in terms of connectivity speeds is usually the only measure that defines the value end users expect to get in standard form retail contracts that are the industry norm around the world. Since this parameter is typically specified in terms of a soft performance target (i.e. maximum link speed), end users can only evaluate if they are getting what they are paying for after they have incurred the fixed costs of entering into a contractual arrangement with the sellers. If the gap between the expected and actual speeds is high, end users will have difficulties deploying 2nd generation Internet applications that require high speed connections. It is the widespread diffusion of such applications that is of particular importance for long term convergence of legacy communications platforms to the Internet (e.g. voice, broadcasting, computing, etc.).

In broad terms, this state of affairs is inefficient from an economic perspective because the risk that actual quality might be substantially below expectations is placed only on one side of the contract (i.e. end users). Although some network providers might be very good at optimizing installed capacity in response to congestion, estimating future demand, and provisioning sufficient network resources to satisfy this demand, other operators may be prone to inefficiency and decision errors (i.e. invest in projects when they should not and not invest when they should; Type I & II errors). Inherent quality uncertainties in the market provide less efficient firms with an opportunity to exploit these uncertainties on shared network infrastructure to gain a competitive advantage over actual or potential suppliers of high quality access services. In addition to lower consumer surplus in terms of the ability of end users to deploy network intensive applications, this can reduce aggregate productivity of the industry and is not necessarily good for investors in telecommunications infrastructure.

Technologies, business models, and public policies that constrain the scope for failing to deliver advertised speeds are not only relevant for protecting consumers in a market where competition may not be feasible, but more importantly, may enhance productive efficiency of the system by increasing the pace of creative destruction as old platforms are replaced by new. Owners of sunset platforms that cannot offer very high-quality/speed services due to technological limitations have particularly strong incentives to over-promote the capacity of their services relative to operators of more advanced networks, better designed to meet end user demand for high-capacity, available, and reliable connectivity. Strong evidence supporting this hypothesis has been detailed in a recent study of Internet connectivity in the European Union, which found the gap between advertised and actual speeds on legacy copper/DSL systems is substantially (around 25%) higher than those end users experience on cable broadband and fiber-to-the-premises (FTTP) platforms (European Commission, 2013, p. 61).

Incentives of legacy platform providers to over-estimate the quality of service they purport to offer end users can have important implications for the evolution of the physical infrastructure that supports the Internet. In the very long term, reductions in the fixed costs of deploying next generation fiber networks will enable both incumbents and potential entrants to deliver the type of high-capacity broadband systems necessary for the widespread diffusion of applications that require high connectivity speeds. If owners of older and lower quality platforms can successfully act as if their offerings are sufficient for end users to benefit from all the marvels the Internet has to offer, they can:

- extend the period over which they can accrue free cash flows from their prior investments in access networks;
- employ misleading advertising as a strategic tool that serves to create noise about the quality of their products relative to actual/potential competitors with higher quality networks.

In addition to usual concerns about consumer protection, these considerations indicate that the potential for misleading advertising by low quality players in the market can distort platform competition and reduce the pace of technological change in the market for Internet connectivity. Given these concerns over the past few years a variety of technological and regulatory responses to the problem have emerged and/or been proposed. For example, various tools have become available that enable even novice end users to monitor the performance of their connections, verify contractual performance by operators, and compare competing service providers. Some of these tools have been developed as stand alone business models (e.g. Ookla/Speedtest, SamKnows), while others are provided by content and application delivery companies that rely on high quality connectivity to reach end users they are trying to serve (e.g. Google/YouTube, Netflix, Akamai).

In terms of public policy, some regulatory agencies have started to collect and publish information about broadband speeds that helps enhance market transparency and promote consumer choice (FAULHABER, 2010). Competition agencies and the courts have also become increasingly involved, issuing practice guidelines and imposing civil fines on more egregious violators of general legal prohibitions against misleading advertising in the provision of Internet access services. We are not aware of any countries that have so far employed their telecommunications regulatory authority to address uncertainties in the manner in which quality is specified in retail contracts between service providers and end users (i.e. from maximum theoretical link speeds to average, median, or minimum speeds for example). Adoption of this type of policy would have obvious implications for operators of legacy platforms, which have stronger incentives to hide the true quality of their services than investors/managers in next generation networks. In addition to technical challenges in changing industry standards of signaling quality in retail contracts, mandating reform through regulation may not be politically feasible because those with fixed investment in sunset technologies/lower quality platforms will have strong incentives to resist it.

Nevertheless, adopting contractual norms with harder performance targets seems particularly important in a network industry where competition may not be feasible or economically desirable. [4] The existence of large scale and scope economies in the operation and management of broadband infrastructure tends to generate monopolistic/oligopolistic market structures at the platform level, limiting the options that users with relatively high demand for network resources have if they observe that advertised service quality does not meet their expectations and decide to find a higher quality supplier (i.e. at most one DSL, cable or fiber platform operator). The impetus for vertical integration is also strong in telecommunications (e.g. with broadcasting, content production), which adds additional strategic incentives for infrastructure operators to de-prioritize applications and content flows that compete with their offerings in high traffic periods. [5] From a partial equilibrium perspective structural dominance and vertical integration may be efficient and inevitable organizational arrangements in platform industries such as telecommunications. However, they may accentuate the tendency for deceptive dealings to drive out transparent ones out of the market. Game theoretical models that emphasize incomplete information problems of consumers suggest that the inefficiencies caused by the Lemons Problem do not necessarily vanish as a result of competition or repeated interactions (LÓPEZ ZORZANO *et al*., 2012).

LI & LIN (2010) present a general theoretical model that helps characterize strategic behavior of platform providers. The model links service quality, capacity constraints, and the competitive landscape relevant

[4] As it can lead to too much duplication and overinvestment in fixed network assets. See RAJABIUN & MIDDLETON (2015).

[5] e.g. Video content from third parties or interference/blocking of peer-to-peer (P2P) traffic.

for the analysis of the market for Internet access services. They show that in information technology markets where service quality depends on other participants (i.e. network effects on platforms), the optimal contract design depends on the structure of the market. In monopolistic environments, they argue that in a world where Service Level Agreements (SLAs) are perfectly enforceable it would be optimal for the platform operator to offer customers only a single type of agreement (i.e. high quality), as customers will not want the low quality alternative. This hypothesis stands in sharp contrast to the usual model of industrial organization in economics where perfect price discrimination is the optimal strategy of a monopolist because it allows the firm to capture the entire market surplus from the consumer. In a duopolistic setting which is more representative of the evolution of broadband markets (i.e. legacy versus next generation platform), the model suggests that operators have incentives to differentiate service level agreements and it would be optimal for lower quality providers to actually advertise a service quality below the level their installed capacity allows them to deliver end users. This hypothesis clearly contradicts evidence from the European broadband markets noted above which shows operators of sunset/low quality broadband access networks exhibit relatively strong preferences for advertising speeds that are not routinely delivered (European Commission, 2013, p. 61). The basic reason for this contradiction between theory and practice is that the LI & LIN (2010) model assumes that service contracts are perfectly enforceable. This assumption might be valid with respect to other platform markets, but asymmetric information about quality and imperfect contracting is the norm in the market for broadband access services. This opportunity apparently alters the optimal strategy set of low quality providers in multi-platform broadband access markets as they tend to advertise quality levels that are above what they are actually able to deliver to their subscribers (given how much they have invested in excess network capacity in the past).

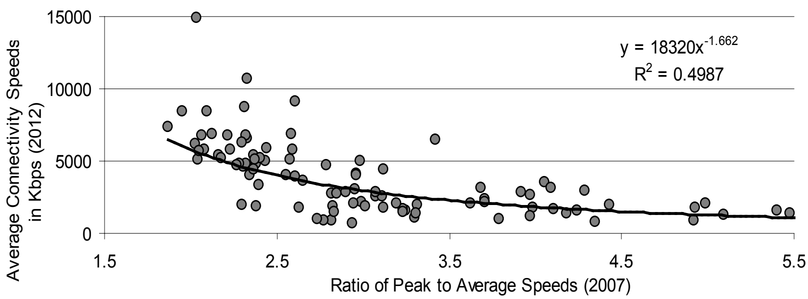
Besides data collection efforts by some governments to evaluate the extent of the gap between advertised and actual speeds noted above, there has been little empirical research that tries to shed light on the causes and consequences of imperfect contracting and asymmetric information between end users and service providers. A notable exception to this is the contribution by SLUIJS *et al*. (2011) who employ a novel experimental method to investigate the impact of quality uncertainty and mechanisms for promoting transparency in the provision of broadband access services. Their results lend some support to the existence of the Lemons Problem. Specifically, in their experimental market more information about quality results in both higher consumer surplus and total efficiency relative to alternative information regimes for structuring transactions, including no-information, imperfect signaling, and mechanisms where only a subset of buyers have access to truthful information about quality. Furthermore, the quality provided by the firms generally increases with the level of transparency about product quality.

The empirical analysis that follows in the next section extends the discussion with a cross-country assessment of the links between variability and quality in the evolution of Internet connectivity. The analysis employs a unique dataset of broadband network performance measurements from a large number of countries between 2007 and 2012 to evaluate the interaction between digital infrastructure quality variability and differences in broadband speeds. The data for this research has been compiled from the logs of the global system of servers operated by Akamai Technologies to deliver content services and more advanced Internet applications to end users.

Since Akamai's Content Delivery Network (CDN) is relatively large (carrying around 30% of Internet traffic), the data offers a unique window into the world of Internet connectivity that is particularly relevant for specifying the service quality end users actually receive from their network operators when deploying 2nd generation Internet applications that require reliable high-speed connections (EZELL *et al*., 2009). The dataset spans a period during which network intensive applications became more available to more end users, leading to a significant increase in demand for network resources particularly by residential customers (BAUER *et al*., 2012). Akamai's data is especially valuable because it allows us to generate digital infrastructure quality indicators of both high and low load states of broadband systems, as well as examine how the gap between these states has evolved over an extended period.

Figure 1 provides a global overview of the potential link between quality of Internet connectivity (as indicated by connectivity speed) and its variability in the past (as reflected in the ratio of peak to average speeds) based on a sample of 100 countries from Akamai. There is a clear negative association between the two indicators, which lends some initial support for the Lemons Hypothesis in the context of internet infrastructure development: Countries with lower variability between high/low load states of the system appear to have developed relatively higher quality networks. A power law relationship represents the best empirical model for fitting the data relative to other standard empirical models (i.e. linear, exponential, etc.). This is potentially relevant for making predictions about how broadband systems in particular countries evolve over time as power law models often simplify complex interactions between various factors which can also shape network development, including variation in the costs of deploying networks, demand intensity, market structure, public policy, and other institutional differences across diverse societies that make up the global sample. The next section extends the discussion by focusing on the more homogeneous sub-set of OECD countries and explores the relevance of the problem by controlling for the potential impact of these variables.

Figure 1 - Quality variability and network infrastructure performance



Source: Akamai Technologies

■ Evolution of internet connectivity in OECD Countries: 2007-2012

Due to substantial differences in the state of digital infrastructure development across the global sample and lack of consistent international data to use as controls, the analysis will focus only on OECD countries. For simplicity we will also assume that underlying interactions can be approximated reasonably well as linear relationships. Given the apparent non-linearity of global data in Figure 1 this would not be a good assumption if we wanted to predict the impact of particular factors, but the objective here is only to determine the existence, direction, and significance of possible relationships. For prediction a non-linear model as above might be more appropriate, particularly for countries where average speeds are relatively low (along the long tail; i.e. developing countries where demand for available network resources outpaces supply relatively more, generating significantly higher gaps between normal/average and peak speeds).

This article looks at the experience for the subset of more advanced economies on the left hand side of Figure 1, where 1st generation broadband networks are widely available and the focus of telecommunications firms and policymaker has increasingly turned to the challenges facing the transition to 2nd generation/next generation fiber networks (BELLOC *et al.*, 2012). Indicators of broadband speeds/service quality employed here are compiled from measurements that represent speeds detected by Akamai during application and content delivery for relatively network intensive applications. This makes the measures informative in terms of understanding how operators have responded to growing demand for network resources, but it is obviously a narrow view of the quality of internet connectivity end users experience. There are also significant differences in the technical design and aggregation procedures in various sources of broadband speed measurements commonly used in business and policy discussions. A review of these differences is beyond the scope of this paper but is provided by BAUER *et al.,* (2010). For example, it is well known that in absolute terms test results from Akamai and another notable test bed (M-Lab's NDT) tend to be around two times lower than those published by another private provider of speed measurements (Ookla Net Metrics/Speedtest). Because of debates about absolute measures of broadband performance various governments around the world have started to implement independent test beds in order to monitor the gap between actual and advertised performance.

Although no measure of broadband speeds and quality of experience is perfect, indicators from Akamai are likely to have less of a sample selection bias than user generated speed measurements (e.g. Ookla/Speedtest, NDT), are available for the longest period for capturing institutional change in the industry, and offer a measure of the installed capacity base when demand for network resources is low (i.e. no congestion state). This allows us to build indicators of both service quality and its variability for a relatively large number of countries and reduces methodological concerns about different approaches to broadband speed measurement in absolute terms. It would be useful to have provider level indicators that we could then analyze with respect to firm specific technologies, strategies, and performance. However, confidentiality considerations limit the scope for further disaggregation of the analysis.

Descriptive statistics: quality variability and the impetus for consumer policy

Table 1 summarizes the indicators from Akamai's global measurements for OECD countries, as well as those relating to control variables included in the regressions that follow in the subsequent sub-section. Peak speeds (PeakS) refer to an average of maximum measured connectivity speeds per IP address by Akamai's CDN and represent an indicator of the state of network when demand is very low (i.e. after midnight). Average speeds (AvgS) represent service quality when most end users require network resources and congestion is the norm (i.e. late afternoons and evenings; see BAUER *et al.*, 2012 for a detailed empirical analysis of the evolution of broadband traffic patterns). Native congestion avoidance mechanisms in TCP/IP and specific flow control algorithms operators must install to manage scarce network resources in high load periods degrade service/quality speeds end users can achieve. This in turn limits the incentives of end users to adopt more network intensive applications because their broadband connections do not deliver sufficient connectivity quality/speeds. In contrast to studies that focus on measuring the gap between advertised and actual speeds, this analysis offers a more general approach to characterizing quality variability as the ratio of peak/low load to average/high load states of the system (Qvar). Indicators of broadband speeds/quality of service are in Mbps and their growth rates are presented in terms of annualized averages (AvgG, PeakG).

To evaluate the statistical relevance of the negative association between variability and quality suggested by the Lemons Hypothesis and sketched in Figure 1, it is necessary to control for other factors that can potentially explain variations in internet infrastructure quality across countries. These include an indicator of the technological landscape/ level of platform competition (non-DSL) and advertised speeds (AdvS), which are compiled and published by the OECD (2012). The variable non-DSL is the sum of the share of the broadband subscriptions for fixed cable and fiber network operators. Given that the market for telecommunications equipment is internationally competitive and network deployment expenditures are partly a function of how far people live from each other, the proportion of the population living in urban areas serves to control cross-country variations in costs. (UrbanR; source: CIA Fact Book, 2013). Differences in demand intensity are captured by data from the International Telecommunications Union (ITU, 2012) on the proportion of regular internet users in the population. A measure of internet use intensity that would reflect differences in the level of technological convergence would be helpful to have for this analysis (e.g. % of population watching TV, downloading music on the internet), but comparative international data of this sort does not seem to have been yet compiled/made available by the relevant international organizations. The Telecommunications Regulatory Governance Index (TRGI) by WAVERMAN & KOUTROUMPIS (2011) serves as a control for variation in the institutional environment for the operation of the market. This index includes various dimensions reflective of the design of telecommunications regulations, policy environment, and income differences that may be relevant for explaining cross-country differences in internet access infrastructure quality.

Table 1 - Summary statistics - OECD countries (N=34)

Variable	*Mean*	*Median*	*STDEV*	*Minimum*	*Maximum*
AvgS (2012)	5.9	5.7	2.3	2.8	14.9
PeakS (2012)	24.6	24.4	6.5	13.9	47.8
Qvar (2012)	4.4	4.3	0.8	3.2	6.6
AdvS	18.6	15.9	13.6	3.1	76.8
AvgS (2007)	3.5	3.2	2.0	1.1	12.9
PeakS (2007)	8.0	7.4	4.0	3.2	26.2
Qvar (2007)	2.4	2.3	0.4	1.9	3.7
TRGI	52.8	58.0	14.8	10.0	74.0
UseR	77.9	81.0	14.1	38.0	96.0
UrbanR	77.2	79.5	11.6	50.0	97.0
Non-DSL	37.3	38.6	22.2	0.1	88.2
AvgG	17.8	17.6	8.3	3.9	39.1
PeakG	53.6	51.8	17.7	19.5	100.3

The mean and median for most of the variables are relatively close to each other, which suggest the presence of a normal distribution. [6] Before

[6] Levels of fiber and cable in national broadband markets are not normally distributed by themselves, highlighting that in a sub-set of countries incumbent DSL operators face significantly more platform competition from relatively higher speed cable and fiber platforms operators, while relatively monopolistic market structures are common in others. By adding the proportions of the market for cable and fiber we address the problem of non-normal distribution in their allocation across countries by creating a single non-DSL indicator, which is normally distributed over the OECD sample. Furthermore, it is important to note that measures of speeds operators advertise in particular markets are not distributed normally and average advertised speeds tend to be substantially higher than the median (OECD, 2012, Table 5a). This suggests service providers usually offer more subscription packages at the higher quality end of the market. This indicates more homogeneity in the range of retail agreements at the lower end of the market, lending further support to the hypothesis that the existence of the Lemons Problem generates "race to the bottom" incentive processes in the provision of Internet access networks.

decomposing the impact of particular variables on broadband development, it is pertinent to highlight a number of observations the summary statistics illustrate that are of particular relevance for understanding the links between quality uncertainty, market efficiency, and public policy:

- Advertised speeds are substantially higher than average measured rates of speed, but are lower than those achievable when demand for network resources is low (peak speeds). This helps explain widespread perceptions of the existence of false advertising in contractual arrangements that commit sellers only to a maximum theoretical speed that may or may not be achievable when most people want to use the internet. [7]

- The gap between high/low load states of broadband systems increased significantly during the five year period (nearly doubled). This illustrates the extent to which the adoption of more network intensive applications by end users has forced network providers to install increasingly more excess network capacity over time. The apparent increase in the variability of service quality helps explain and justify policy concerns about inaccurate advertising, network management practices of the operators, and their ability to meet growing demand for network resources.

- Growth in peak network speeds outpaced that of average speeds by a large margin. To increase speeds/service quality by 1% in average/normal traffic periods, operators on average had to increase excess capacity/available slack in the system by around 3%. Best performing countries in improving digital infrastructure quality nearly doubled peak network capacity/performance on an annual basis, while the rate of annual peak capacity enhancements was as low as 20%.

Quality uncertainty and digital infrastructure quality

Global data presented in Figure 1 suggest a negative non-linear relationship between variation in the quality of broadband internet access connectivity and differences in network infrastructure quality around the world. There are however, a wide range of other factors that could plausibly explain international variations in digital infrastructure quality. As documented in Table 1, even within advanced economies there are

[7] Countries with the highest performing networks were Korea and Japan. In these leading countries end users could achieve speeds that were nearly 4 times faster than those in lowest performing countries in OECD (e.g. Mexico, Turkey) and around 2 times faster than countries with average/median speeds in the middle of the group (e.g. U.S., Canada).

substantial differences in service quality/speeds end users are able to achieve. In addition to quality variability (Qvar), other explanatory variables that seem relevant include geography/costs of network deployment (UrbanR), demand intensity (UseR), regulatory and policy institutions (TGRI), and platform competition (non-DSL). Median advertised speeds (AdvS) are also included in the regressions to evaluate their association with actual measured speeds of access networks.

Table 2 - Determinants of internet access infrastructure quality in OECD countries

	Model A		*Model B*		*Model C*	
	y = AvgS (2012)		*Y = PeakS (2012)*		*Y = Qvar (2012)*	
	Coef.	p-value	Coef.	p-value	Coef.	p-value
Intercept	7.0464	0.0234	21.3370	0.0354	2.9905	0.0063
Adv. Speed	0.0613***	0.0047	0.1339*	0.0504	-0.0053	0.4458
TRGI	-0.0018	0.9118	-0.0175	0.7479	-0.0039	0.4969
UseR	-0.0026	0.9149	-0.0363	0.6505	-0.0197**	0.0250
UrbanR	0.0244	0.3153	0.0735	0.3567	0.0013	0.8758
non-DSL	0.0421***	0.0011	0.1676***	0.0001	0.0000	0.9953
Qvar (2007)	-2.2546***	0.0091	-3.0673	0.2549	1.2939***	0.0001
Adj. Rsq		0.6903		0.5811		0.7158

Statistical significance levels of 1%, 5%, and 10% are denoted by ***, **, and * respectively.

The three multiple regression models (A, B and C, presented in Table 2) explain somewhere between 60 to 70 percent of observed differences in digital infrastructure quality and the level of quality variability across OECD countries. One reason why R-Squared indicators are not higher might be the non-linearity of underlying relationships, which the least squares method simplifies (as suggested in Figure 1). There may also be some omitted variables, as well as inadequacies in the proxies employed here to control for other variables with a potential impact on broadband infrastructure quality.

Model A investigates the determinants of the average quality of internet connectivity and provides a basis for evaluating the relevance of the Lemons Problem in the development of network access platforms in OECD countries. Controlling for various indicators of costs, demand intensity, and market governance, the negative impact of the variability/uncertainty about service quality remains statistically significant (at the 1% level). We can therefore reject the null hypothesis that there is no relationship between uncertainty and quality (i.e. reject no Lemons problem). Countries where quality variability/uncertainty has been lower appear to have developed relatively high quality broadband networks for accessing the internet. Platform competition and the level of advertised prices also have a statistically significant impact on observed measures of average broadband infrastructure quality.

Model B explores the determinants of broadband network quality when there is little demand by other end users in the vicinity for network resources on shared links and switching facilities (PeakS). Cross country differences in peak capacity appear to be primarily driven by competition from the diffusion of non-DSL platforms and the level of advertised speeds. The magnitude of the impact of platform competition on measured network quality in low traffic periods (Model B) is substantially higher than on average performance rates (Model A). The positive association between advertised and actual speeds in both models may reflect the existence of an upper bound to the ability of network operators to promise service quality levels that they cannot later deliver.

Model C looks at the impact of the explanatory variables on the extent of quality uncertainty/variability (Qvar). There is little association between advertised speeds and other control variables beside past quality variability on the extent of quality variability in the future. Exploring potential causes of quality variability across countries and firms represents an avenue for future research relevant for both policymakers and investors in telecommunications infrastructure. Indicators of the institutional and policy environments (TRGI), geography/cost variation (UrbanR), and demand intensity (UseR) do not appear to be associated with measures of broadband network quality or its variability in OECD countries. This does not imply that policy and costs factors are irrelevant, only that the proxies employed here to account for their impact on internet connectivity may not be very informative in this setting.

■ Summary and implications

Business and economic history is replete with examples in which asymmetries in knowledge about the attributes of particular goods and services lead to a situation in which the bad drives out the good, generating a full scale market failure and/or inefficient low quality market equilibriums (AKERLOF, 1970). This type of process can occur in a relatively competitive market such as that for used cars, but can represent a particularly pernicious problem in network industries that exhibit structural dominance where consumers usually have a choice between only one or two suppliers. If low quality platform operators are able to act as if the levels of service they offer end users are better than what they can actually deliver given their capacity constraints, they can exploit the opportunity as a strategic tool to dilute signals from high quality firms. Previous research on the market for internet access services documents that the gaps between advertised and actual service quality/speeds of operators that rely on legacy copper/DSL networks tend to be substantially higher than inherently faster/higher quality cable and fiber platforms (EC, 2013). Others have shown the implications of information asymmetries and the existence of the Lemons Problem in the provision of internet access services, highlighting the importance of public policies that encourage transparency for promoting broadband market efficiency (SLUIJS *et al*., 2011).

This article takes quality variability to be an inherent and potentially irreducible element of internet access services on shared infrastructure subject to congestion. It extends the discussion by analyzing broadband quality and its variability in OECD countries. Controlling for a wide range of potential determinants of internet connectivity speeds, the analysis confirms the negative link between uncertainty and quality in the provision of broadband access services. The analysis suggests public policies that promote transparency about actual service quality and/or promote the adoption of more informative performance targets in retail contracts could have a positive impact on the incentives of access providers to meet growing demand for network resources. Rapid growth in the gap between high/low load states of broadband systems documented here illustrates the impact of the diffusion of 2nd generation internet applications on quality variability over the past few years and explains why concerns about discrepancies between advertised and actual network performance have become more pronounced.

Beyond debates about economic theory and telecommunications policy, this analysis also has some implications for businesses/consumers that require reliable high-capacity internet connections, as well as for strategic decisions by potential and actual investors in next generation broadband networks. Because operators of sunset platforms have relatively strong incentives to over-promote the capacity of their products, it is particularly important for end users and businesses that rely on this class of firms for connectivity to monitor and verify the service quality they are getting relative to levels specified in service contracts. Since informed consumers are more likely to choose the high quality product if prices are the same, a shift to contractual standards that involve more informative expected service quality benchmarks (versus the current maximum theoretical link speeds) represents one approach to enhancing the credibility of commitments by service providers. Given that organizations with fixed assets in legacy platforms benefit more from the existence of imperfect contracting than their high quality rivals, they would have incentives to resist any regulatory mandates that force operators to employ more informative metrics for defining expected quality in retail contracts. Even if it is not technically or politically feasible to address the imperfect contracting problem across the industry, it might be profitable for high quality firms to voluntarily offer potential consumers a more informative quality signal and stronger/more concrete contractual commitments to quality standards particular end users can expect from their service provider. If this "honesty strategy" succeeds in motivating a sufficient number of end users to switch from low to high quality platforms, it would help enhance the pace of creative destruction towards the adoption of next generation technologies.

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