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Drivers of fixed and mobile broadband infrastructure adoption and quality

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Drivers of Fixed and Mobile Broadband Infrastructure Adoption and Quality

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Abstract

The benefits of advanced information and communication services are increasingly dependent on the quality of the available connectivity. This paper examines the factors that influence the quality of fixed and mobile broadband access in OECD countries. Drawing on institutional economics, the study provides an integrated conceptual framework that allows analyzing the interaction of supply, demand, policy, and contextual factors. We explore the drivers of broadband access and quality and potential interdependencies between them. Our focus is on the role of public policy decisions as a determinant of quality and quality upgrades of fixed and mobile access networks. We also find evidence that regulatory interventions such as unbundling or open access provision do have a positive contribution in markets with limited competition. However, the findings also provide evidence that the best policy approach is dependent on the specific context of a country so that no single best practice model emerges from the observations.

Keywords: Broadband quality, unbundling, open access, competition, spectrum policy

JEL Codes: L51, L86, L88, L96

1. Introduction

With the rapid diffusion of mobile and fixed access platforms, access to broadband services has become widely available in high and medium-income countries. While overcoming gaps in broadband access remains an important and pressing policy issue, the realization of the benefits of advanced information and communication services is increasingly dependent on the quality of the available connectivity. Faster access speeds are widely seen as a prerequisite to utilizing the potential benefits of advanced communications technology. As the fixed and mobile Internet is increasingly used for real-time entertainment purposes, users also demand higher download speeds. Policy makers worldwide seek to facilitate the deployment faster broadband but there continues to be a vigorous debate as to the best path to meet this goal and how fixed and mobile broadband can contribute to it.

Fixed and mobile broadband are in a multi-faceted relationship. To some degree and for some users they are substitutes but for many users they are complements. However, these relationships will depend on quality attributes and prices. Faced with constraints on investment funds, network operators with a presence in both market segments will seek to allocate funds in response to market and policy conditions. The quest for increasing quality is therefore complicated by the complex relation between fixed and mobile platforms. In spite of the increasing importance of quality attributes most theoretical and empirical studies of broadband availability have thus far focused on adoption. Only a handful of recent papers have sought to address the factors influencing broadband infrastructure quality (e.g., Bauer, Schneider, & Zenhäusern, 2013).

This paper examines the factors that influence the quality of fixed and mobile broadband access. Drawing on institutional economics, it provides an integrated conceptual framework that allows analyzing the interaction of supply, demand, policy, and contextual factors. This approach allows differentiated insights into the effects of policy choices and their interactions with other factors. Policy instruments that are examined in detail include forms of unbundling and open access, the creation of competitive conditions, and the importance of public-private partnerships. For mobile broadband, we also control for aspects of spectrum policy and management. As is known from policy research, it is often a specific combination of policy choices that affects outcomes rather than any single measure. Prior empirical research suggests that the implementation of a consistent combination of policy choices matters greatly (Künneke, Groenewegen, & Ménard, 2010).

To address this unique interaction of policy arrangements with outcomes, we pursue a dual approach using empirical methods that allow complementary insights. The application of panel methods allows the examination of sufficient conditions and of effect sizes of drivers of broadband quality. A second method, Qualitative Comparative Analysis (QCA), pioneered by sociologists and political scientists, allows the systematic exploration of interdependencies among these drivers. This quantitative method is better suited than traditional econometric models to explore the interactions between policy choices and the quality of broadband access. QCA allows a systematic examination of the necessary and/or sufficient conditions that influence broadband quality. Because the method is based in principles of set theory, it allows a flexible analysis of not only single policy instruments but also of their interaction with other policy and external conditions.

We explore the drivers of both fixed and mobile broadband quality and potential interdependencies between the developments of them. Using Akamai data of download speeds that are actually realized over the network infrastructure for a cross-national sample of OECD and medium-income countries, we focus on the role of public policy decisions as a determinant of quality and quality upgrades of access networks. The paper contains theoretical, empirical and practical contributions. Theoretically, it provides a more comprehensive analysis of the factors that shape broadband speeds. Empirically, it applies a dual approach, combining Qualitative Comparative Analysis (QCA) and regression analysis to communications policy issues. Because this approach allows exploring the levers available to policy-makers more fully than econometric analyses alone, the paper also contains directly applicable practical lessons for policy-makers.

The remainder of the paper is organized as follows. The next section briefly explores the development of fixed and mobile broadband. Section three presents the conceptual framework utilized in our research. Section four discusses the empirical approach and the subsequent section five the main findings. A concluding discussion of policy implications and reflections on next steps aimed at improving the findings are offered in section six.

2. The development of fixed and mobile broadband

The relationship between fixed and mobile broadband adoption is not a priori clear. Both platforms can, to some degree, meet the same needs for high-speed connectivity. This would suggest that they are in a substitutability relation, one service competing against the other. At the same time, each of the platforms provides features that are only incompletely present in the other platform: mobility on the one hand and ultra-broadband capability on the other. This would

suggest that, while fixed and mobile can be substitutes under some conditions, they will be complements in other circumstances. At an aggregate level, empirical evidence suggests that they are complements (Lee, Marcu, & Lee, 2011). This is also supported by recent trends in network development, as an increasing number of service providers integrate fixed and mobile platforms by combine next-generation passive optical networks (NG-PON) and fourth generation wireless (4G) into next-generation hybrid fiber-wireless (FiWi) infrastructures (Ali, Ellinas, Erkan, Hadjiantonis, & Dorsinville, 2010). This perspective is also visible in the increasing number of service providers who offer integrated service plans that combine multiple platforms.

Empirical data reveals that mobile and fixed broadband access is positively related ($r = .52, p < .01$) but there are considerable variations among countries, as illustrated in the scatterplot of fixed and mobile broadband penetration rates (see Figure 1). Fixed and mobile adoption follows different patterns in that fixed is typically subscribed by households whereas mobile is subscribed on an individual bases. Nonetheless, Figure 1 suggests that in some countries mobile seems to play more of the role of a substitute whereas in others is can be regarded as a complement.

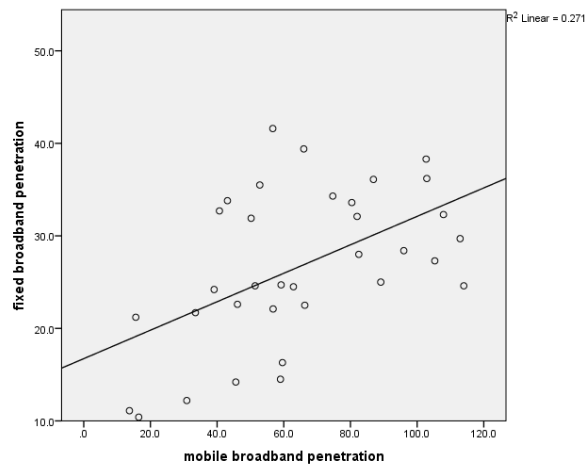


Figure 1: Fixed and mobile broadband penetration rates

The positive relation between the two platforms is also visible with regard to average download speeds ($r = .80, p < .001$, Figure 2). However, the relationship is strongly influenced by Korea (the observation located on the right upper side of Figure 2) and it would be less clear cut if only the other countries were taken into account.

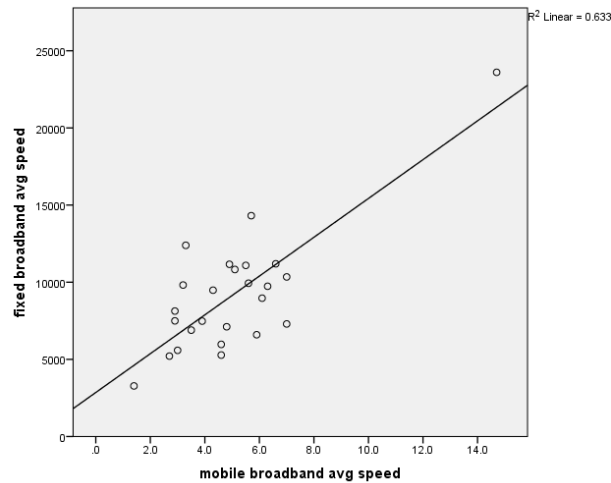


Figure 2: Fixed and mobile broadband average speeds

Interestingly, as Figure 3 illustrates, no strong relationship can be found between fixed and mobile broadband peak speeds ($r = .10, n.s.$). Rather, there is significant variation and outliers in both fixed and the mobile platforms.

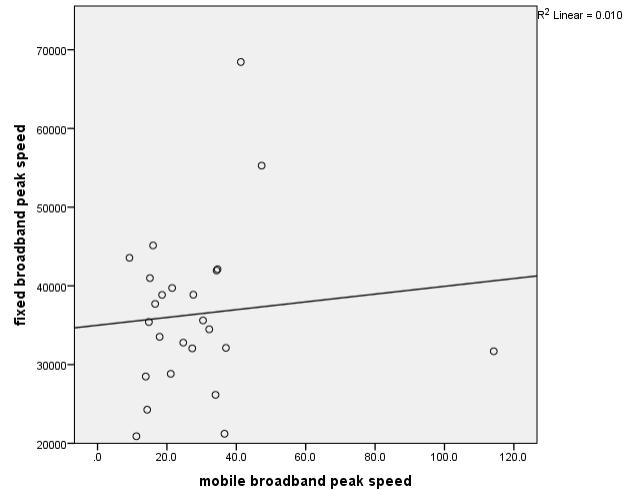


Figure 3. Fixed and mobile broadband peak speeds

3. Policy choices and broadband quality: A conceptual framework

The received literature also provides important insights into the factors that influence broadband quality. However, existing research can be improved in two major aspects. First, it would be desirable to have an integrated theoretical model of the determinants of broadband quality. Second, most of the existing literature models the interaction between public policy choices and broadband in overly simple ways, largely ignoring the fact that most policies occur in combinations. This section briefly sketches how the present paper attempts to overcome both limitations.

Broadband quality ultimately is the outcome of actions by private and public network providers, whose investment and innovation decisions affect quality attributes throughout the entire communications infrastructure system. Other things being equal, if communications investment levels in a country are low during extended periods of time, one would expect to observe lower broadband quality (and vice versa). A more fully developed theoretical model can

therefore be formulated by examining the investment and innovation decisions of network operators and service providers in quality. As the provision of higher quality requires resources and, despite a strong trajectory of continuous technological advances, is costly, commercial and not-for-profit service providers will weigh the benefits and costs of making an investment in a quality upgrade by looking at discounted future cost and revenue streams, adjusted for unique risks and options (Alleman & Noam, 1999). In turn, future revenues and costs will be influenced by supply and demand-side factors in broadband markets, and public policies affecting broadband (J. M. Bauer, 2010). They may also be affected by broader economic, social, and technical forces, such as the speed of technological change. Consequently, four sets of forces will influence broadband quality: supply-side conditions, demand-side conditions, policy choices, and control factors.

From the perspective of an individual network operator, the provision of network quality can be seen as a decision to differentiate available service offerings to better serve user groups with heterogeneous needs and hence improve revenues. The most important supply-side factor that influences broadband quality decisions will be the intensity of competition in the broadband market. One can hypothesize that more intense competition will provide stronger incentives to differentiate quality both by offering higher-end services at a higher price and lower-end services at a lower price. Moreover, the level of quality will be influenced by the costs of providing it. Hence, it will tend to be higher in low-cost, densely populated areas and lower in high-cost, sparsely populated areas. Lastly, supply of quality will depend on the costs of rolling out higher quality. With technological change reducing the cost of components and software, one would expect a steady trajectory of quality improvements due to technological advances (J. M. Bauer et al., 2013).

The second set of factors influencing the emergent broadband network quality attributes will arise from demand side conditions. Prior literature has identified willingness to pay and price for broadband as the most important factors on the demand side. Willingness to pay is, in turn, influenced by income and the decision makers' perception of the benefits derived from broadband access. Other things being equal, higher income goes hand in hand with higher demand for broadband and broadband quality. Likewise, other things being equal, lower prices for a given level of quality are associated with higher demand as more households are willing to purchase broadband access (Larose et al., 2012; NTIA, 2011). Demand is also affected by other factors. For business users demand is, to a large degree, derived from a firm's operations and business model. Residential demand is influenced by socio-demographic factors, some closely related to income, such as the level of education, race, ethnicity, and age. Effective demand for broadband is also a function of digital literacy and self-efficacy, which are preconditions of recognizing the potential benefits of broadband access and being able to realize them. Both these factors are also associated with income levels (Larose et al., 2012).

The third major set of factors is public policy. Improved quality is seen as one of the desirable consequences of policy choices. However, while most policy decisions have implications for quality, few are designed explicitly with quality in mind. For example, competition is supported with the goal to increase efficiency, of which quality is one component. Advanced communication systems are affected by several overlapping realms of public policy that are not always well coordinated and integrated: traditional regulatory policy, Internet governance, overarching plans directed at supporting broadband and a digital economy, and competition policy. For the past three decades, traditional regulatory policy has been concerned about mitigating market power of the historical monopoly service providers and managing a

transition to a more competitive market environment for communications. Main instruments utilized to achieve these ends were price controls, measures facilitating market entry, and open access policies such as local loop unbundling and interoperability requirements. Of the set of regulatory policies, universal service is the one instrument most directly aiming at improving quality attributes of infrastructure, either by expanding access to remote locations and disadvantages user groups or by upgrading the services supported by the infrastructure.

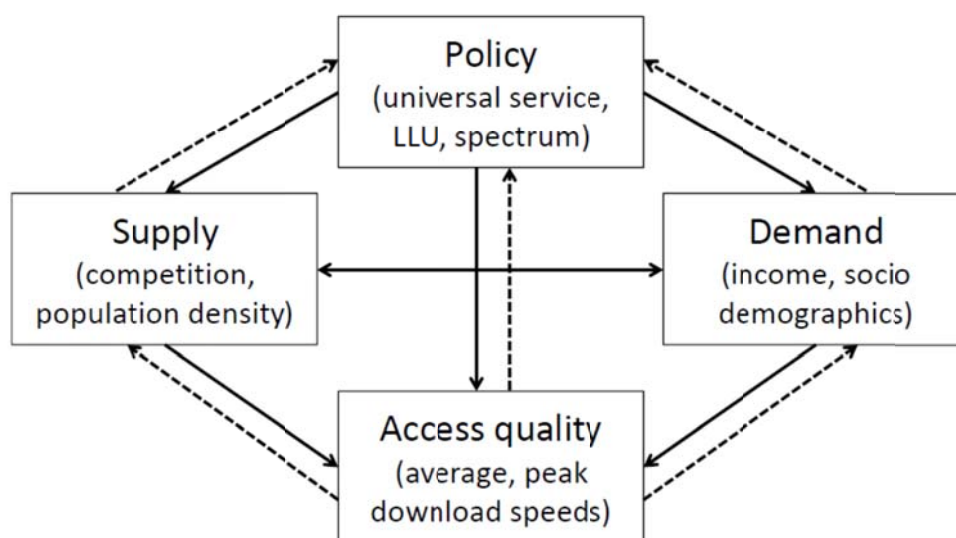


Figure 4: A stylized model of the determinants of access quality

Internet governance is complementary to these policies but emerged and remains located in a largely separate set of institutions that bring together actors from the private sector, civic society, and government (e.g., ICANN and its supporting organizations, the Internet Governance Forum, and W3C). Decisions made in these forums, from numbering conventions to protocols such as the transition from IPv4 to IPv6 all have indirect implications for infrastructure quality. Network quality is most directly addressed in national and local broadband plans (e.g., FCC,

2010). Many nations, states, and municipalities have defined benchmarks for the envisioned access speeds that the communications infrastructure should support.

A second weakness of prior research has to do with methodological assumptions. Most prior research tacitly postulates that policy instruments such as unbundling or universal service plans act as separate variables on outcomes. In other words, the theoretical and, in empirical studies, methodological assumption is that these variables are sufficient conditions for an outcome. While this is possible, it must not be assumed but rather tested. Certain policy choices may only be sufficient in combination with other choices or they may constitute necessary but not sufficient conditions. Unraveling these relations requires a differentiated and comprehensive understanding of the processes of complex causation in socio technical systems (see Figure 5). A factor is a sufficient condition of an outcome, if its presence is associated with the outcome. It is a necessary condition of the factor is present whenever the outcome is observed but if it can also be associated with other outcomes. Multiple factors are jointly sufficient, if their joint presence ascertains an outcome. They are jointly necessary if there are present whenever an outcome is observed. In order to influence a socio technical system, policy makers need to know the structure of these relations.

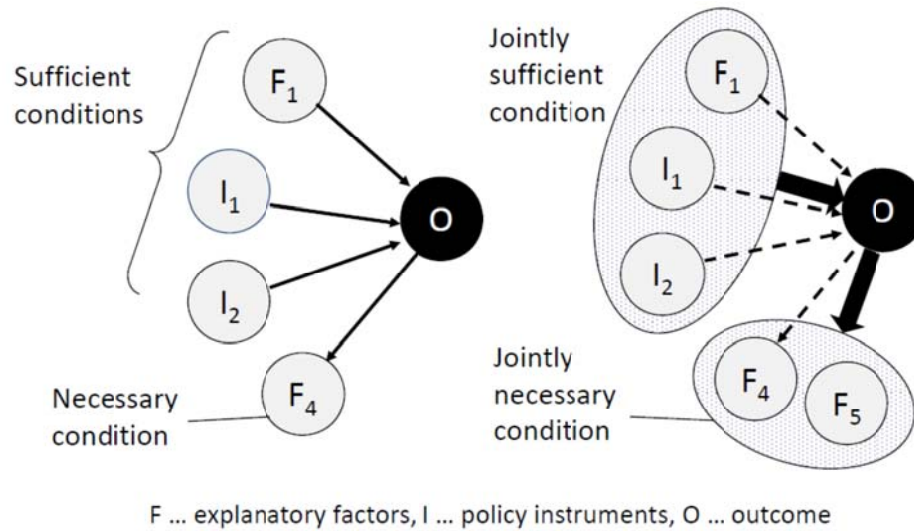


Figure 5: Complex causation in socio-technical systems

However, such a differentiation is not possible with traditional econometric tools, which are commonly utilized in studying these issues. Therefore, the dominant empirical approach in the literature on the determinants of broadband adoption is at odds with our body of knowledge of how institutional arrangements (one of them being policy choices) affect outcomes in socio economic and socio technical systems. Much of that vast body of studies in economics, political science, sociology, and history suggests that policies affect outcomes as constellations, as combinations that jointly affect outcomes. While one specific instrument such as universal service obligations may not be effective on a stand-alone basis, it may be effective if used in combination with educational measures. Moreover, policies interact with the context in which they are adopted. For example, unbundling may not be effective all the time, but only in it is used in a highly concentrated market environment.

From a theoretical and methodological point of view this means that in addition to asking whether independent variables are sufficient to achieve an outcome, one also has to ask whether they are sufficient in combinations (joint sufficiency) and whether they are necessary

conditions, individually or jointly with other factors, to achieve a desired outcome. The method of Qualitative Comparative Analysis (QCA), discussed more fully in the next section, can achieve such a fine-grained analysis. This knowledge is of immediate relevance for policy makers and a precondition for effectively governing any socio technical system, including broadband quality. If sufficient conditions exist, policy will be able to successfully shape outcomes if these conditions can be manipulated. However, if a combination of factors is jointly sufficient, all of them need to be modified successfully to achieve an outcome, a much more challenging task. Likewise, if factors constitute necessary conditions, policy makers will have to be able to influence them all so that an overall consistent policy combination can be put into place (Künneke et al., 2010). There is increasing evidence that it is the failure to implement the required combinations of factors that derails most well-intended policy initiatives. Hence, knowing which kinds of interventions will most likely succeed is critical.

4. Empirical approach and methods

In order to examine the interaction of the regulatory, supply, and demand factors that affect broadband quality, qualitative comparative analysis (QCA) will be used to analyze the data. The core theoretical foundation of QCA is sets theory (Ragin, 1987). QCA can be seen as a combination of quantitative and qualitative analyses. All predictors will be put together as combinations of conditions to examine how these conditions related to the outcomes of interest (Basurto, & Speer, 2012; Rihoux & Ragin, 2009). QCA has been applied to examine political, environmental, and issues. It can help researchers explore the complexity of various conditions and examine what kinds of conditions are necessary or sufficient for the outcomes to be present.

There are many kinds of QCA, such as crisp sets QCA and fuzzy sets QCA (fsQCA). In this study, fsQCA will be conducted. In fsQCA, all conditions and outcomes will be calibrated to present their degree of membership (Ragin, 2000). Their membership is an interval between 0 and 1. Zero represents a non-membership, 0.5 represents the maximum ambiguity of membership, and 1 represents a full membership (Ragin, 2008).

To conduct an fsQCA analysis, the first step is to do calibration. After calibrating the degree of membership for all conditions and outcomes, a truth table needs to be generated. Truth tables indicate all possible conditions and outcomes. The next step is to analyze necessary and sufficient conditions by using the truth tables. For sufficient conditions, three kinds of solutions can be generated by using fsQCA software: complex, intermediate, and parsimonious solutions. For all solutions, consistency and coverage scores are used to describe their quality. Consistency presents how cases with same conditions agree in the presence of the outcomes. Coverage indicates how much the combinations of conditions explain the outcomes (Ragin, 2008).

4.1 Data collection and analysis

The regulatory, demand, and supply-side factors for 34 OECD countries were collected from the OECD database, ITU website, World Bank, and World Trade Organization (WTO). The data for the outcome variables, infrastructure quality of fixed and mobile broadband, were collected from AKAMAI website. FSQCA 2.0 software was used for analyses.

4.2 Measures

All measures are also listed in Appendix A.

Fixed Average Download Speeds (FBSpeed). Fixed broadband speed data were collected from the Akamai website using the actual speeds captured in Q1, 2014.

Mobile/Wireless Average Download Speeds (WBSpeed). Mobile broadband speed data were collected from the Akamai website using the actual speeds captured in Q1, 2014.

Broadband Universal Service (USO). Countries with broadband universal service were coded as 1 and countries without broadband universal service were coded as 0.

Local Loop Unbundling (LLU). LLU is operationalized as a dummy variable that captures the presence of local loop unbundling for fiber, cable, and DSL. Countries with all three kinds of LLU received a score of 3, countries in which LLU was mandatory in two market segments received a 2 for having two kinds of LLU services, etc. Having no LLU requirement in a country, the membership value will be .05.¹ The country with three kinds of LLU was calibrated to 0.95 (full membership). The cut-off point is having one kind of LLU requirement.

Cost (proxied by Population Density, PD). Population density was collected from the United Nations (<http://data.un.org/Data.aspx?d=PopDiv&f=variableID%3A14>) (year 2010). It was calibrated by using the minimum population density of OECD countries as 0.05 (non-membership) and the maximum as 0.95 (full membership). The average of population density was calibrated to .05.

Fixed Broadband Competition (FHHI). Competition was measured by using an inter-platform HHI (Herfindahl–Hirschman Index). The inter-platform HHI was calculated by squaring the subscriptions for each broadband technology (including DSL, cable, fiber, and

¹ To avoid problems with QCA, a very small positive value was assigned instead of zero.

other) divided by the total subscriptions of all technologies, and then adding all of these squared values (see below):

$$HHI = (S_{DSL}/S_{total})^2 + (S_{cable}/S_{total})^2 + (S_{fiber}/S_{total})^2 + (S_{other}/S_{total})^2$$

with S_{total} = subscriptions of all technologies

The minimum HHI was calibrated to .05 and the maximum was calibrated to .95, while the average score was calibrated to 0.5. The data was collected from the OECD Communications Outlook.

PPP. The information about Public-Private Partnerships (PPP) was collected from the ITU website with 1= with PPP and 0=without PPP.

Spectrum Policy - Technology Neutrality. One indicates the presence of this policy, while 0 indicates the absence of this policy.

Spectrum Policy - Spectrum Sharing. One indicates the presence of this policy, while 0 indicates the absence of this policy.

LTE License Availability. One indicates the presence of this policy, while 0 indicates the absence of this policy.

Wireless Competition (WHHI). Wireless network competition was utilized to present the competition for mobile broadband. Intra-platform HHI (Herfindahl–Hirschman Index) was calculated by squaring the market share for each wireless operator (see below):

$$WHHI = (MS_1/MS_{total})^2 + (MS_2/MS_{total})^2 + (MS_3/MS_{total})^2 + (MS_4/MS_{total})^2 + (MS_5/MS_{total})^2 \dots$$

with S_{total} = total market share of all operators presented

The minimum HHI was calibrated to .05 and the maximum was calibrated to .95, while the average score was calibrated to 0.5. The data was collected from the OECD Communications Outlook.

Income. Gross national income per capita was collected from the OECD website. Income was calibrated by using the minimum income as 0.05 (non-membership) and the maximum as 0.95 (full membership). The average of income of OECD countries was calibrated to .5.

Education. Portions of populations with tertiary education attained by ages 25-64 were used for the measure of education (OECD, 2013). Education was calibrated by using the minimum as 0.05 (non-membership) and the maximum as 0.95 (full membership). The average of education of OECD countries was calibrated to .5.

5. Empirical results and findings

Both fsQCA and multiple regression were performed to examine what might be better predictors of broadband speeds. For fsQCA, FSQCA 2.0 (2009) software was used for QCA analyses. The open software package is available at <http://www.u.arizona.edu/~cragin/fsQCA/software.shtml>. The necessary and sufficient conditions for having higher fixed and mobile broadband average download speeds were analyzed. For the multiple regression analyses, SPSS 20.0 was used to perform the analyses.

5.1 fsQCA

5.1.1 Necessary conditions for high access speeds

The analyses of necessary conditions showed that having higher mobile broadband speeds,

Table 1: Necessary conditions for high fixed and mobile broadband access speeds

	Fixed Broadband		Mobile Broadband	
	Consistency	Coverage	Consistency	Coverage
WB	0.809349	0.850674		
FB			0.850679	0.809349
LLU	0.854286	0.613648		
PPP	0.351951	0.418182		
BBSUO	0.268587	0.481667	0.208245	0.384000
USO	0.890714	0.402258	0.98170	0.424583
PD	0.694286	0.745971	0.640659	0.668342
FHHI	0.538571	0.548763		
WHHI			0.560697	0.673611
INCOME	0.809767	0.756812	0.823593	0.748649
EDU	0.847857	0.700295	0.783241	0.660439
TECHN			0.951698	0.448276
SHARE			0.765827	0.407273
LTE			0.319152	0.400000

LLU, universal service, higher income, and higher education were necessary conditions to have higher fixed broadband speeds (see Table 1). Having higher fixed broadband speeds, universal service, higher income, and technology neutrality policy were necessary conditions for having higher mobile broadband speeds.

5.1.2 Sufficient Conditions for high access speeds

5.1.2.1 Fixed broadband

Three kinds of solutions were generated by using fsQCA analyses: complex, parsimonious, and intermediate solutions. For fixed broadband speeds, three combinations were found sufficient for having higher fixed broadband speeds (see Table 2). Countries with high income, high education, universal service, LLU, higher wireless speeds, higher inter-platform competition, no PPP, and no broadband universal service could have higher fixed broadband speeds (condition 1 in Table

2). However, countries with lower wireless speeds, with broadband universal service, higher population density, higher inter-platform competition, LLU, universal service, and no PPP can also have higher fixed broadband speeds (condition 2 in Table 2).

Table 2: Sufficient conditions for fixed broadband: Complex and intermediate solutions

	Raw coverage	Unique coverage	Consistency
1. WB*~FHHI*~PPP*LLU*~BBUSO*USO*INC OME*EDU	0.316934	0.316934	0.945392
2. ~WB*~FHHI*~PPP*LLU*BBUSO*USO*PD* INCOME*EDU	0.062929	0.062929	0.873016
3. WB*~FHHI*PPP*LLU*BBUSO*USO*~PD*I NCOME*EDU	0.094966	0.094966	0.922222
Solution coverage: 0.474828; solution consistency: 0.930493			

Looking into the parsimonious conditions (Table 3), we notice that having higher fixed broadband HHI (which means, higher inter-platform competition) was an important criteria. With higher competition and either LLU policy, higher income, or higher education, a country can have higher fixed broadband speeds.

Table 3: Sufficient conditions for fixed broadband: Parsimonious solutions

	Raw coverage	Unique coverage	Consistency
1. ~FHHI*LLU	0.836385	0.058352	0.844111
2. ~FHHI*INCOME	0.774600	-0.000000	0.865729
3. ~FHHI*EDU	0.759726	0.020595	0.856774
Solution coverage: 0.875286; solution consistency: 0.786228			

5.1.2.2 Mobile broadband

The complex solution showed that there were two combinations could yield to higher mobile broadband speeds. Both of these conditions had higher fixed broadband speeds, technology neutrality policy, higher wireless network competition, universal service, lower population density, and higher income. Condition 1 had spectrum sharing policy, LTE license, and higher education, while condition 2 did not contain any of these (see Table 4).

Table 4: Mobile broadband sufficient conditions: Complex solution

	Raw coverage	Unique coverage	Consistency
1. FB*TECHN*SHARE*LTE*~WHHI*USO*~PD*INCOME*EDU	0.331011	0.33101 1	0.865854
2. FB*TECHN*~SHARE*~LTE*~WHHI*~B BUSO*USO*~PD*INCOME*~EDU	0.158512	0.15851 2	1.000000
Solution coverage: 0.489524; solution consistency: 0.905172			

Based on the parsimonious solutions, we found that having lower population density, with either higher wireless network competition, or higher fixed broadband speeds could be the simplest solutions for having higher mobile broadband speeds (see Table 5).

Table 5: Mobile broadband sufficient conditions: Parsimonious solution

	Raw coverage	Unique coverage	Consistency
1. ~WHHI*~PD	0.972054	0.156181	0.723958
2. FB*~PD	0.827528	0.011655	0.903308
Solution coverage: 0.983709; solution consistency: 0.722603			

According to the intermediate solutions, we found that having high income, low population density, high wireless competition, technology neutrality policy, higher fixed broadband speeds, either with or without high education, spectrum sharing policy, and

availability of LTE licenses, a country could still have higher mobile broadband speeds (see Table 6).

Table 6: Mobile broadband sufficient conditions: Intermediate solution

	Raw coverage	Unique coverage	Consistency
1. EDU*INCOME*~PD*USO*~WHHI*LTE* SHARE*TECHN*FB	0.331011	0.331011	0.865854
2. ~EDU*INCOME*~PD*USO*~BBUSO*~W HHI*~LTE*~SHARE*TECHN*FB	0.158512	0.061335	1.000000
Solution coverage: 0.48952; solution consistency: 0.905172			

5.2 Regression analyses

Multiple regressions were also performed to examine the relationship among the regulatory, supply, demand factors and the average fixed broadband and mobile broadband speeds (see Table 7).

Table 7: Descriptive statistics

	N	Minimum	Maximum	M	SE
WB	25	1.4	14.7	5.02	2.51
FB	34	3276	23603	8784.12	3695.71
PPP	32	0	1	0.34	0.48
LLU	34	0	3	1.32	0.81
HHI	34	0.35	1	0.57	0.18
BBUSO	27	0	1	0.22	0.42
PD	34	2.88	484.07	133.94	125.25
INCOME	32	14982.1	61345.9	33487.93	11328.33
EDU	34	13.1	50.6	30.69	9.91
USO	34	0	1	0.91	0.29
TECHN	25	0	1	0.80	0.29
SHARE	20	0	1	0.75	0.44
LTE	23	0	1	0.43	0.51
WHHI	33	0.25	0.53	0.34	0.06

5.2.1 Fixed broadband

For fixed broadband, the average speed of mobile broadband, PPP, LLU, HHI for fixed broadband, the availability of broadband universal service, the adoption of universal service, population density, income, and education were included in the model. Among these variables, the speeds of mobile broadband (Beta = .437, $p = .01$), fixed broadband HHI (Beta = -0.273, $p < .05$), and population density (Beta = .496, $p < .01$) were significant. The total model had $F(9, 9) = 12$, $p = .001$, $R^2 = .923$, adjusted $R^2 = .846$

Table 8: Multiple regression on fixed broadband speeds ($N = 19$)

	B	SE	Beta	t	Sig.
(Constant)	4374.662	3482.34		1.256	0.241
WB	7.00E+02	216.542	0.437	3.234	0.01
PPP	987.613	1155.036	0.11	0.855	0.415
LLU	-388.15	785.743	-0.063	-0.494	0.633
FHHI	-6888.17	2740.632	-0.273	-2.513	0.033
BBUSO	-957.597	1324.618	-0.094	-0.723	0.488
USO	-1878.7	2417.293	-0.101	-0.777	0.457
PD	15.977	3.951	0.496	4.044	0.003
INCOME	0.071	0.055	0.158	1.288	0.23
EDU	84.496	50.469	0.197	1.674	0.128

$F(9, 9) = 12$, $p = .001$, $R^2 = .923$, adjusted $R^2 = .846$

5.2.2 Mobile broadband

For mobile broadband, the average speed of fixed broadband, technology neutrality, spectrum sharing, the availability of LET licenses, wireless network HHI, the availability of broadband universal service, the adoption of universal service, population density, income, and education

were included in the model. None of these variables were significant predictors of mobile broadband speeds in this model ($F(9, 1) = 6.074$, $p = .306$, $R^2 = .982$, adjusted $R^2 = .82$).

Table 9: Multiple regression on mobile broadband speeds (N = 11)

	B	SE	Beta	t	Sig.
(Constant)	16.955	7.954		2.132	0.279
FB	0	0	-0.442	-1.215	0.438
TECHN	-5.998	2.361	-0.974	-2.541	0.239
SHARE	-3.641	1.356	-1.094	-2.685	0.227
LTE	1.183	1.173	0.384	1.009	0.497
WHHI	-21.789	11.845	-0.514	-1.84	0.317
BBUSO	-0.407	0.865	-0.106	-0.471	0.72
PD	-0.011	0.003	-0.774	-3.536	0.175
INCOME	9.77E-05	0	0.568	2.11	0.282
EDU	0.055	0.037	0.359	1.496	0.375

$F(9, 1) = 6.074$, $p = .306$, $R^2 = .982$, adjusted $R^2 = .82$

6. Discussion

We find that the most important factor with a positive effect on both fixed and mobile broadband quality is competition. Although neither fixed broadband HHI or mobile network HHI were necessary conditions for having higher broadband speeds, both of them were shown as one of the condition in the sufficient conditions. For fixed broadband, having higher inter-platform competition and LLU policy was one of the parsimonious solutions for having higher fixed broadband speeds (See Table 2.2). For mobile broadband, having higher mobile network competition and lower population density was one of the parsimonious solutions for having higher mobile broadband speeds (Table 3.2). Accordingly, we also find evidence that regulatory interventions such as unbundling or open access provision do have a positive contribution in markets with limited competition. However, the findings also provide evidence that the best

policy approach is dependent on the specific context of a country so that no single best practice model emerges from the observations.

Another interesting finding is the relationship of population density and broadband speeds. Population density can be and was used as an indicator for the costs to build up broadband infrastructure. According to the result of multiple regressions, we found that population density was positively related to fixed broadband speeds. This indicated that countries that had higher population density (lower cost) had higher fixed broadband speeds. However, for mobile broadband, the meaning of population density might have another implication. A country with lower population density might imply the lower availability of fixed broadband infrastructure or fewer people might be using mobile broadband in the same area at the same time. This could also imply that the relationship between fixed broadband and mobile broadband was not as straightforward as it was shown in the regression analyses.

The data used for the analyses had certain limitations. First of all, these data were cross-sectional data. Therefore, there is a possibility of reversed causality. Researchers might consider using panel data to test the direction of causality. Secondly, using population density as an indicator of cost might not be the perfect way to represent the costs. In this study, we found that population density was positively related to fixed broadband speeds, but negatively related to mobile broadband speeds. The role of population density plays in predicting mobile broadband speeds is interesting and also is worth further examination.

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This paper builds on and significantly expands earlier work, some of which was presented at conferences before (but has not been published). A first attempt to model fixed broadband quality was presented at the European Regional Conference of the International Telecommunications Society in Florence (October 2013) and a preliminary discussion of QCA with a more limited sample will be presented at the CPR LATAM conference in Bogotá (May 2014) and TPRC 2014. We thank participants at these conferences for valuable feedback. Compared to these earlier versions, the present paper adds mobile broadband and used the latest speed data for the analyses.

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Appendix A. Measures

Variable	Abbreviation	Sources	Definition
Fixed Broadband Average Download Speeds	FB	Akamai	Average download speeds measured in Q1, 2014
Mobile/Wireless Broadband Average Download Speeds	WB	Akamai	Peak download speeds captured in Q1, 2014
Broadband Universal Service Objectives	BBUSO	OECD, ITU, Regulatory websites	Countries with broadband universal service were coded as 1 and countries without broadband universal service were coded as 0.
Universal Service Adopted	USO	ITU	1= present, and 0=absent
LLU	LLU	OECD Communications Outlook	(1) the presence of LLU for fiber, cable, and DSL
LTE License Availability	LTE	ITU	1= present, and 0=absent
Spectrum Policy-Technology Neutrality	TECHN	ITU	1= present, and 0=absent
Spectrum Sharing	SHARE	ITU	1= present, and 0=absent

Cost (Population Density)	PD	United Nations (http://data.un.org/Data.aspx?d=PopDiv&f=variableID%3A14)	Population Density
Fixed Broadband Competition	FHHI	OECD Communications Outlook	Inter-platform HHI (Herfindahl–Hirschman Index)
Wireless Competition	WHHI	OECD Communications Outlook	Intra-platform HHI (Herfindahl–Hirschman Index) for wireless networks
Income	INCOME	OECD website	GDP
Education	EDU	OECD website	Portions of Populations with tertiary education attained by ages 25-64 in year 2010
