Telematics and Informatics 32 (2015) 230–244

Contents lists available at ScienceDirect

Telematics and Informatics

journal homepage: www.elsevier.com/locate/tele

Regulation, investment and efficiency in the transition to next generation broadband networks: Evidence from the European Union

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ARTICLE INFO

Article history:
Received 1 March 2014
Received in revised form 24 July 2014
Accepted 3 September 2014
Available online 10 September 2014

Keywords:
Broadband Internet
European Union
Regulation
Technological change

ABSTRACT

This article explores the impact of public policy on technological change and the development of broadband infrastructure in EU member countries. The analysis explores contradictory findings in previous empirical literature on the interplay between regulation, competition, and investment, noting the importance of the construction of indicators employed to evaluate these interactions. Furthermore, the article points out that the traditional policy model and related empirical literature treat fixed capital inputs in networks as a measure of broadband infrastructure quality. However, relatively higher capital inputs do not necessarily translate into the development of relatively higher quality broadband networks. Using broadband network performance measurements between 2007 and 2012, the article addresses this contradiction in the literature and evaluates the determinants of broadband infrastructure quality in the EU. The analysis suggests countries that have been more effective at promoting entry and competition in the provision of Internet access services have developed relatively higher quality broadband networks.

1. Introduction

This article investigates the relationship between public regulation and the development of broadband infrastructure in member states of the European Union. Understanding this link is important because of the potential for private sector under-investment in capacity upgrades or in rolling out new platform technologies. Poorly designed access regulations could exacerbate the under-investment problem, while efficiency enhancing regulations can encourage risk sharing and industrial cooperation that might be necessary for overcoming the fixed cost problem that limits the potential for the diffusion of new platform technologies (Cambini and Silvestri, 2012; Krämer and Vogelsang, 2012). This article asks if and how regulatory diversity in the member states can explain differences in the quality of broadband Internet connectivity end users experience in the EU.

Recent international studies on the impact of public policy on broadband network development highlight an empirical puzzle that is particularly relevant for the design of regulations that support the transition to next generation connectivity. There is some evidence that access regulations, requiring facilities operators to interconnect with third parties so that third parties can deliver services using existing facilities, are negatively correlated with capital expenditures on fixed assets at the national level and by incumbent network operators (Grajek and Roller, 2012). This observation is important from a policy

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http://dx.doi.org/10.1016/j.tele.2014.09.001
0736-5853/

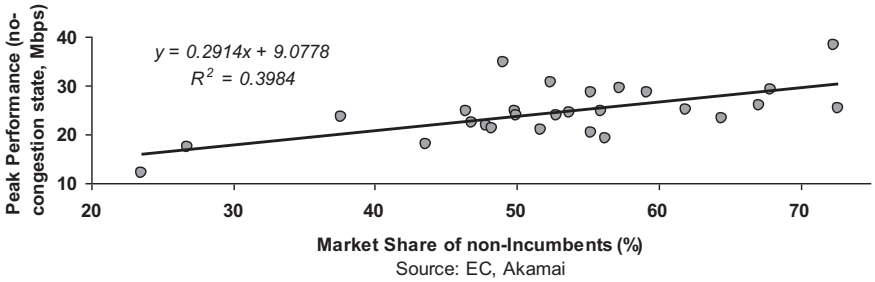

Fig. 1. Entry and network quality in the EU.

perspective because inter-platform competition (facilities-based, not access-based) has been an important driver of broadband penetration growth in advanced economies over the past decade (Bouckaert et al., 2010). These results have led some observers to argue that open access policies (allowing interconnection) are not desirable because they reduce incumbent operators' incentives to invest in network facilities that operators may have to share with others. On the other hand, there is also some evidence that countries with open access policies (which creates service-based, or intra-platform competition) have developed higher quality broadband systems (Berkman Center for Internet, 2010; Choi, 2011).

This contradiction suggests that higher levels of capital inputs do not always translate into a higher rate of network capacity improvements, presumably because there is some efficiency loss due to a lack of competitive discipline and/or risk sharing in the presence of demand uncertainties. Too much inter-platform competition can also imply too much duplication, which could further help explain why some countries with relatively high capital expenditures on telecoms do not necessarily have relatively high quality network infrastructure (Rajabiun and Middleton, 2013a). This article explores the broader empirical puzzle in the context of the experience in the European Union. The ambiguous policy implications of previous research are of concern since they limit the scope for evidence-based decision making. This is particularly important for the design of future policies that might be necessary for overcoming the under-investment problem so as to achieve specific minimum quality of service targets that various governments have recently adopted (e.g. 30 Mbps in the EU), diffusion of next generation access networks (NGNs), and attempts to build a single telecoms market (Kroes, 2013).

This article argues that a key problem with previous quantitative studies is that their dependent variables are not a very good reflection of broadband network quality end users' experience, especially in maturing markets where near universal access to 1st generation broadband technologies has already been achieved. The research has primarily focused on analyzing the impact of access regulation and market competition on investment and/or past broadband penetration levels. Although penetration rates may have been a good indicator of market outcomes in the transition from dial-up to broadband, the actual quality of service end users achieve represents a more realistic indicator for measuring the pace of progress in the diffusion of next generation platform technologies. Furthermore, fixed capital expenditures are only one of the many inputs into the process and their impact on network outcomes will depend on the ability of operators to translate them into capacity upgrades and new technology deployments. Firm specific internal factors such as managerial efficiency and technical expertise, as well as external constraints imposed by competitive discipline on network providers, are likely to influence the efficiency by which capital inputs improve network quality. As Fig. 1 illustrates, the recent experience in EU member states lends some support to the hypothesis that countries where incumbents face more competition in the market tend to have developed relatively higher quality broadband networks.[1]

The objective of the article is to help reconcile some of the gaps in the literature by focusing on the impact of national regulatory strategies within the EU on the pace of progress in broadband network quality improvements. Section 2 provides an overview of the empirical puzzle in the context of the standard model for the analysis of competition and regulation in network development. Section 3 reviews previous studies and explores their relevance using a wide range of indicators that help capture some of the cross-country variation in regulatory regimes, competitive environments, and investment patterns in EU members. Section 4 investigates the association between capital expenditures, diffusion of more advanced broadband platforms, and the quality of Internet connectivity end users experience. Section 5 concludes by drawing inferences for the design of national and EU level policies intended to promote universal access to next generation connectivity over the next decades.

2. Motivation for the research: competition, regulation, and efficiency of network investments

As technological innovation made it more difficult to sustain the traditional regulated monopoly model in telecommunications, by the late 1990s and early 2000s most advanced economies adopted broadly similar policy strategies to shape telecommunications infrastructure development (Noam, 2010). In addition to liberalizations and privatizations of that period, most countries also adopted a relatively similar set of formal regulatory obligations on incumbent operators of copper tele-

[1] For description of the data in the figures and the empirical analysis that follows see the Appendix to this article.

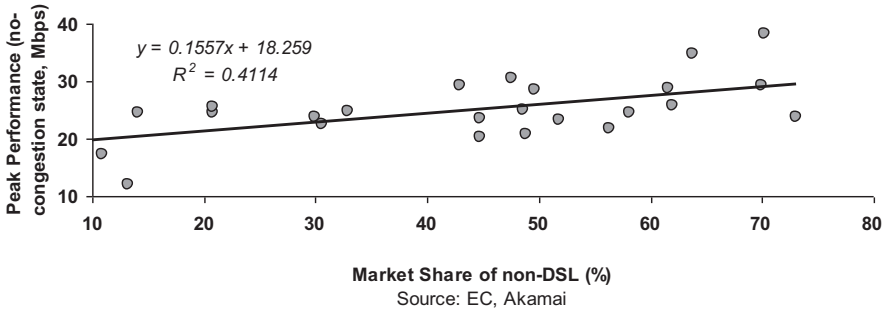

Fig. 2. Inter-platform competition and network quality in the EU.

phone networks to unbundle their local loops and provide potential third party entities access to particular components of the network deemed essential by the policymakers (OECD, 2008). The level of subsequent commitment by policymakers to the implementation of these rules has been more diverse. For example, U.S. and Canada were among the first countries to adopt formal unbundling rules and related policies aimed at creating a wholesale market in the provision of telephone and network access services. Since the 1990s however, regulators in advanced economies have diverged in their approach and degree of commitment to the implementation of third party access obligations (OECD, 2008). In Japan and Korea policymakers have adopted relatively credible third party open access rules, but have also had to co-opt incumbent industrial interests with large public subsidies for the provision of high-capacity backbone and fiber access infrastructure (Choi, 2011). Concerns about under-investment in some European countries have also motivated their governments to allocate scarce public funds to broadband development (European Commission, 2013). Others have tried to promote infrastructure development by imposing structural separation policies on incumbents, in the hope that this reduces their incentives for exclusionary conduct and forces them to become more efficient through specialization (e.g. U.K., Italy, Sweden, Finland, and Poland). At least since the mid 1990s, questions about regulatory centralization and the scope of EU telecom policy authority have been a key element of debates about Internet infrastructure development (Sun and Pelkmans, 1995; Lehr and Kiessling, 1999).

There is a large empirical literature that studies the impact of access regulations and other policy instruments on investment, innovation, and growth in access to broadband Internet connectivity, a review of which is beyond the scope of this paper. The reader can turn to Cambini and Jiang (2009), Bauer (2010) and Belloc et al. (2012) for insightful overviews. While evidence on the interplay between regulation and investment is mixed (Cambini and Jiang, 2009), previous studies document that supply side policies that enable third parties to access essential facilities are associated with faster growth in broadband penetration; particularly in the early stages of network development and in maturing markets where penetration rates start to reach a maximum threshold (Belloc et al., 2012). As illustrated above in Fig. 1, countries with a higher degree of service-based competition in the EU also appear to have developed relatively higher quality broadband networks in terms of the speed of connectivity end users experience. In addition to the positive empirical association between service-based competition and broadband infrastructure quality, previous international studies further document that penetration growth and network quality and speeds tend to be higher in countries with a higher degree of inter-platform competition (Ware and Dippon, 2010; Bouckaert et al., 2010; Rajabiun and Middleton, 2013b). Fig. 2 illustrates that a positive association between inter-platform competition and network quality has also characterized the recent experience in EU member states (i.e. EU27).[2]

The fact that both service-based and inter-platform competition appear to have a positive association with economic incentives to deliver high quality broadband connectivity provides a basis for understanding the basic dilemma facing policymakers in the design of essential facilities/interconnection regulations. Economic theories of telecommunications suggest that in the short run policymakers can improve economic efficiency by imposing more onerous legal obligations on incumbent platform operators to provide service providers access to components of the network that are considered essential (i.e. static efficiency). These obligations strengthen the incentives for cooperation among potential competitors, reducing prices and increasing the quality of service end users experience (i.e. consumer welfare). The standard economic model of telecommunications policy further captures the idea that pro-competitive regulations intended to enhance cooperation/competition between network platform and service providers are not necessarily optimal in the long term because they can reduce investment incentives (i.e. dynamic efficiency). In theory those who have to share their fixed assets with potential competitors may have lower ex ante incentives to invest in such facilities.[3]

[2] It is relevant to note that the magnitude of positive effect of service-based competition (Fig. 1) on network quality/capacity is around 2 times higher than inter-platform competition (Fig. 2).

[3] For theoretical models of competition, investment, and efficiency consideration that explore this basic framework in regulatory economics of telecommunications networks see Laffont and Tirole (2000) and Kotakorpi (2006).

Table 1
Perceptions of regulatory quality and investment patterns: 2009–2012.

	Model A		Model B	
	y = Per capita investment		*y* = Investment growth	
	Coef.	*p*-Value	Coef.	*p*-Value
Intercept	73.151	0.148	−113.725	0.000
EntrantS	−**2.055*****	0.002	**0.888*****	0.006
UrbanR	0.327	0.493	**0.722*****	0.009
UseR	0.647	0.156	−0.143	0.526
ECTA	**0.258****	0.017	0.055	0.272
Adj R Sq.		0.677		0.525

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

If the objective of the policymakers is to maximize private sector investment in network infrastructure, the traditional policy model provides a logical basis for exercising forbearance from regulating essential facilities access in the name of long term dynamic efficiency. However, the level of capital expenditures is only one determinant of long term broadband market outcomes. The ability and incentives of operators to translate these investments into network quality improvements is particularly important for evaluating the effectiveness of public policy in promoting network development. Because the existence of market power in the short run relaxes the budget constraints facing incumbent platform operators, it can have negative implications in terms of their incentives to deploy capital. For example, incremental investments by incumbents on sunset platforms (i.e. copper/DSL) may appear to be an optimal short term strategy from the perspective of firms that are locked into old technologies (Hoernig et al., 2012). In this context, there would be no reason to expect that countries with relatively high levels of aggregate capital expenditures on networks will eventually develop higher quality networks. A lack of third party access rights to essential facilities and/or regulated prices that are too high can also lead to too much duplication in such facilities, thereby explaining why higher capital inputs may not always translate into a relatively higher rate of network quality improvements. Section 4 will explore the impact of capital expenditures, as well as a number of other institutional and economic factors, on the quality of broadband connectivity end users experience in the EU. The next section first provides an overview of previous studies and uses a variety of indicators to characterize possible links between regulation, competition, and investment.

3. Regulatory diversity and investment patterns in the EU

The process of EU enlargement starting in the 1990s created profitable opportunities for expansion by capital rich incumbent operators in Western Europe to East and Central European markets. Although national governments in Western Europe had previously been reluctant to relinquish any authority over telecommunications to the European Commission, the prospects of entry into new markets altered the balance of interests and led to the adoption of a common policy framework and EU essential facilities access mandate (Directives 2002/21/EC & 2002/19/EC). Prior to joining the EU in 2004, the first round of accession countries faced significant scrutiny and pressure by incumbent EU member states to implement open access regulations and limit the exclusionary tendencies of dominant essential facilities operators. Incumbent EU members did not have the benefit of this external scrutiny and it became increasingly apparent that incentives for the effective implementation of EU rules in some incumbent members are limited (De Bijl and Peitz, 2005).

More recent efforts to enhance digital economy monitoring by the Commission and potentially expand its authority to regulate access to Next Generation Networks (NGNs) should be viewed in this historical context (Ruhle and Reichl, 2009; Simpson, 2011; Montolio and Trillas, 2013). As detailed below, the relationship between regulation and investment in policy debates that have ensued about European telecoms depends very much on the methodology used in constructing cross-country indicators of regulatory differences and characterizing capital expenditures on networks. Variables and sources employed in the analysis that follows are described in the Appendix.

3.1. Perceptions of regulatory quality

Pursuant to the adoption of the EU policy framework and essential facilities obligations prior to the first round of expansion in 2004, access seekers started to face similar problems in accessing essential network components and attempted to coordinate their efforts to influence public policy. Contemporary debates about the links between regulation and investment in the EU policy context can be traced to efforts by the European Competitive Telecommunications Association (ECTA), an association representing market entrants, to capture the quality of national regulatory regimes (ECTA Regulatory Scorecard).[4] The ECTA Scorecard is compiled from surveys of ECTA membership, which includes primarily non-incumbent operators

[4] ECTA is self described as an "association representing the regulatory and commercial interests of 'challenger' electronic communication service providers and their suppliers" by promoting regulations that support "competition, investment, and innovation in the European ICT sector": <http://www.ectaportal.com/en/ABOUT/Why-Join-ECTA/Reasons-to-join-ECTA/>

Table 2
Regulatory intensity and investment patterns.

	Model A		Model B	
	y = Per capita investment		y = Investment growth	
	Coef.	p-Value	Coef.	p-Value
Intercept	122.957	0.077	−5.985	0.815
EntrantS	−**1.684*****	0.004	0.305	0.139
UrbanR	**1.461****	0.010	**0.593*****	0.006
UseR	−0.168	0.784	−0.112	0.632
RegInt	−1.245	0.243	−**1.226*****	0.005
Adj R Sq.		0.478		0.387

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

and network technology firms. Consequently, it captures telecommunications policy quality from the perspective of those who are likely to require access to essential facilities and would benefit from credible obligations on incumbents to cooperate/interconnect with them. Cadman (2007) documented a significant positive association between regulatory quality as captured by the ECTA Scorecard and per capita investments in the telecommunications sector for a sample of 16 EU countries in 2003–2005.[5]

In Table 1 we investigate if the positive association between ECTA's indicator of regulatory quality and per capita investment levels remained relevant following the financial crisis of the late 2000s. Controlling for differences in geography/cost of network deployment, demand intensity, and market structure across the 19 countries for which ECTA compiled an index in 2009, the association with subsequent per capita investment levels (averaged over the next 3 years: 2009–2011) remains positive and statistically significant at the 5% level (Model A, Table 1). The magnitude of the coefficients and their level of statistical significance are lower than those outlined by Cadman (2007) for the period following the collapse of the telecom bubble in the early to mid 2000s. There is little apparent relationship between ECTA measures and growth in capital expenditures subsequent to the financial crisis of the late 2000s (Model B, Table 1). A higher degree of urbanization/costs of network deployment were associated with higher rates of investment growth subsequent to the asymmetric financial shock of the late 2000s.

The negative association between entrants' share of the broadband Internet market (EntrantS) and per capita investments on fixed assets (Model A) helps characterize the empirical puzzle that motivates this article: More competition and entry may reduce investment incentives of infrastructure providers, but higher investments do not necessarily translate into higher network quality/capacity if there is a significant efficiency loss due to a lack of competitive discipline and/or duplication in fixed assets by network platform operators. Although both regressions are significant and explain around 50–70% of variation, given the small sample size for the ECTA Scorecard these results should be treated with caution. The magnitude of the negative impact that competition has on investment is substantially larger than the positive impact of regulatory quality as measured by ECTA (around 8 times).[6] The negative correlation between entry and investment should not be taken to imply causality for three notable reasons:

- *Financial effects*: The crisis of the late 2000s had an asymmetric impact on the costs of borrowing across the EU, with more pressure on Southern Europe than on North/Eastern members.
- *Catch up effect*: EU mandated open access policies that promoted entry in accession countries provided a basis for rapid network development in the mid to late 2000s. As concerns about broadband infrastructure quality in incumbent/non-accession EU members grew, they started to invest more.
- *Reverse causality*: Higher investment levels by incumbents can serve as a strategic deterrent against entry.

3.2. Regulatory intensity

The idea that regulations that enhance the incentives of operators to cooperate with others can increase investment incentives in aggregate terms promoted by ECTA stands in sharp contrast to the traditional policy model that suggests the existence of a tradeoff between static efficiencies (i.e. market power) and dynamic efficiency (i.e. incentives to make irreversible decisions about fixed capital expenditures in network infrastructure). From the perspective of large incumbent operators that have to comply with public rules governing their market behavior and cooperate with potential competitors, the intensity of these obligations represents a key public policy concern. One such measure of regulatory obligations (Plaut Eco-

[5] Notably, the relationship between regulation and capital expenditures turns negative when, instead of the ECTA Scorecard, the OECD's Regulatory Quality Index is used to capture regulatory diversity (Cadman, 2007). The primary reason for this is the construction of the OECD indicator, which implicitly measures regulatory differences using a measure of structural dominance in the market. In other words, the OECD measure captures the organization of the market and not how public policy shapes that structure. See OECD Indicators of Regulatory Management Systems portal: <http://www.oecd.org/gov/regulatory-policy/indicatorsofregulatorymanagementsystems.htm>

[6] Correlation between ECTA Regulatory Scorecard, entrants' share the market, and our control for capturing differences in network deployment costs are insignificant, which limits the potential for multi-colinearity in the regressions.

Table 3
Institutional differences and investment patterns EU27.

	InvG	RevG	Inv/Rev	InvL	NGA	non-DSL
EntrantS	0.09	0.05	−0.09	**−0.59**	**0.39**	**0.48**
Poltrans	0.19	0.23	−0.21	**0.67**	**−0.33**	**−0.47**
Regtrans	−0.12	**−0.28**	0.03	0.03	−0.02	0.15
RegInd	**−0.30**	−0.13	−0.18	−0.09	−0.03	−0.19
RegRes	−0.17	−0.16	−0.02	0.17	−0.15	−0.20
Enforc	−0.23	0.25	**−0.28**	−0.02	−0.23	−0.31
TRGI	−0.23	−0.08	−0.14	**0.40**	**−0.35**	**−0.47**

nomics Regulation Index and its updated version, the Polynomics Regulation Index (Polynomics, 2012) has been employed in a series of studies that challenge the hypothesis about the positive link between open access regulations and broadband infrastructure investments (Zenhäusern et al., 2007; Grajek and Roller, 2012; Bacache et al., 2013). Grajek and Roller (2012) look at industry and firm level capital expenditure in the EU over a 10 year period. They find little association between the intensity/density of regulation and investment levels by entrants, but show more intensive access regulation regimes reduce capital expenditures by incumbents.[7]

Table 2 provides the results of our assessment of the association between regulatory intensity as measured by the Polynomics Index and investment in the EU27 following the financial shock of the late 2000s. While there is a negative correlation between regulatory intensity and capital expenditure levels, this association is not statistically significant when we control for differences in the costs of network deployment and service-based competition (Model A). There is a statistically significant negative link between regulatory intensity and short-term rates of growth in investments following the financial crisis (Model B). This suggests investments recovered faster from the crisis in countries with relatively simple/less intense rules for the regulation of market behavior of dominant operators (versus complex standards).[8]

Overall, regressions using the Polynomics Regulation Index explain a smaller proportion of subsequent variation in per capita investments and capital expenditure growth than empirical models using perceptions of regulatory quality from ECTA with the same controls (Table 1). The degree of service-based competition and urbanization/costs of network deployment appear to explain around half of observed variation in per capita investment levels in the medium term (i.e. 3 year averages). Controlling for regulatory intensity/density (Polynomics) rather than perceived regulatory quality (ECTA) reduces the magnitude and statistical significance of the negative correlation between entry and per capita investment levels. We have also explored potential impact of regulatory intensity on future levels of service-based and inter-platform competition, but did not find a statistically relevant association and do not report the results.

3.3. Institutional design

Beyond the intensity of legal obligations associated with particular implementations of the EU policy framework and access regulation directives by the member states, broader institutional differences in the design of policy processes may help explain how formal legal rules shape economic incentives about fixed capital expenditures on networks. The Telecommunications Regulatory Governance Index (TRGI) by Waverman and Koutroumpis (2011) provides a basis for exploring the relevance of these institutional differences in general terms, as well as along a number of particular dimensions emphasized by the literature on the political economy of regulation. The sub-components of TRGI try to capture a number of subtle, but potentially important, elements of institutional design in telecommunications, including regulatory transparency, independence, resources, and enforcement. The general TRGI indicator incorporates a measure of variation in cross-country differences in per capita income levels, which may make it useful as a control. Telecommunications policy sub-indicators in TRGI were compiled from information provided by policymakers in individual countries to the International Telecommunications Union (ITU). Sub-components are weighed equally to construct the general TRGI indicator. Table 3 documents correlations among various lagged institutional indicators (circa late 2000s) and measures of capital expenditures on networks in EU members during the subsequent years (2009–2012).

This overview of the interplay between institutional variation, nominal investment levels, and technological outcomes in the EU helps highlight the relevance of the empirical puzzle set out in this article, which may help move beyond the traditional model of tradeoffs among static and dynamic efficiencies. Per capita investment levels in monetary terms tend to be lower in countries where entrants have been more successful in taking a larger proportion of the market for Internet access services. However, in markets with a higher share of entrants the diffusion of more advanced broadband platforms (non-DSL, NGA, as defined by the EC) is higher. This dichotomy can also be observed with respect to TRGI and different classes of indi-

[7] We have not been able to verify their results since we have been informed that the original dataset contains proprietary information and is not publicly available.

[8] See Christiansen and Kerber (2006) and Rajabiun (2012) for theoretical and empirical studies on the implications of using simple rules versus complex standards in the design of legal constraints against anticompetitive practices.

cators of capital inputs. Countries that are further along the transition to next generation networks (i.e. higher investment quality in technological terms) have more service-based competition, but score lower on the TRGI. These countries also score lower in terms of the broad measure of perceived political transparency/accountability/anti-corruption, as complied by Transparency International (Poltrans). The fact that TRGI and the Transparency measure both tend to rank Western/Northern European countries higher than Southern/Eastern Europe helps explain these results.

Our analysis does not reveal consistent and statistically significant associations between any of TRGI's individual components and subsequent per capita investment levels in the EU27. Furthermore, the positive association between the aggregate TRGI indicator and per capita investment levels dissipates once we control for differences in the costs of network deployment as captured by the proportion of the population that live in urban areas (i.e. lower deployment costs in more densely populated areas). The negative link between TRGI and both investment growth patterns and inter-platform competition remains robust to cost differences and a number of other controls.

Although the positive correlation between TRGI and differences in the levels of capital expenditures may not be statistically significant once we control for cost differences, per capita investments are clearly higher in countries that were ranked higher on the Transparency International index (i.e. Western/Northern EU member states), even after including various supply and demand side controls. This association provides a basis for explaining the broader puzzle in terms of the legacy of the EU expansion process, the increasing role of European institutions in telecommunications regulations, and the divergence in paths of industrial change across the sample. Prior to their accession to the EU future members had to implement the EU common policy framework and essential facilities regime under the watchful eyes of the Commission and other interested parties in incumbent member states (i.e. incumbent firms or their associated companies trying to expand eastward). This enabled some incumbent operators to become entrants in other emerging European telecom markets. By restricting the ability of incumbent owners of sunset platform technologies (i.e. DSL) to limit access to essential facilities in Central and Eastern Europe the accession process provided a basis for the development of relatively high quality networks with relatively lower levels of fixed capital expenditures. Countries that did not implement EU regulations in an effective manner due to limited top–down monitoring by the Commission fell behind in the mid to late 2000s and have had to catch up subsequent to the financial crisis. Lower labor costs in Eastern/Southern Europe are likely to accentuate the geospatial dichotomy in the underlying data.

Given the asymmetric influence of local incumbent firms on local regulatory decisions, owners of sunset platforms in many West European countries have been relatively more successful in limiting competition from potential entrants with incentives to deploy new technologies. Delays in moving away from legacy DSL platforms in a number of these countries in the mid to late 2000s generated an impetus for various large scale investment initiatives by public and private entities in the aftermath of the financial crisis (see Fig. 3; e.g. Denmark, Luxembourg, Netherlands, Ireland, Italy). To constrain exclusionary tendencies of large incumbents with asymmetric capacity to shape regulatory outcomes relative to their rivals/consumers, a number of countries have taken a relatively more radical approach by imposing structural/functional separation on such entities (e.g. British Telecom, Telecom Italia, TeliaSonera, Telekomunikacja Polska). Research on the impact of separation suggests that this policy strategy has significantly increased the efficiency of such firms (by around 20%) relative to integrated network operators in Europe (Bruno, 2012). The example of structural/functional separation highlights the challenges in aggregating complex policy strategies into reliable cross-country indicators of institutional design, regulatory intensity, or quality.

3.4. Access pricing and other related metrics

From an economic perspective the more direct method for capturing the links between the policy environment and the evolution of the market is to look at the regulated prices of access to facilities that are deemed to be essential. National procedural autonomy in the implementation of the EU policy framework provides local regulators with significant discretion to set prices they think are "reasonable" for operators of local essential facilities to charge third parties who want to intercon-

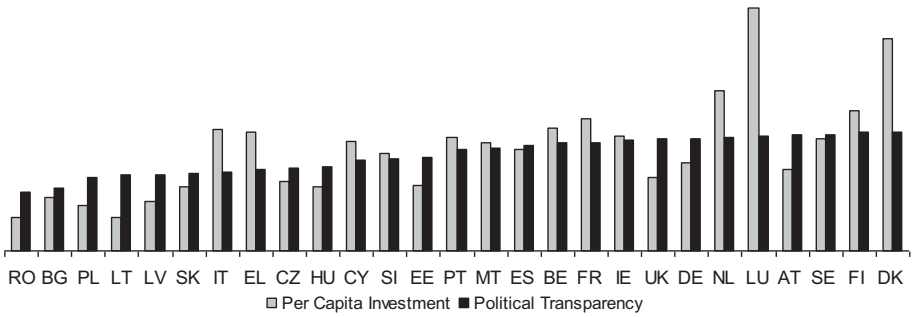

Fig. 3. Investment patterns and perceptions of policy transparency.

nect with particular components of the system. We have studied two indicators of regulated prices (average access prices for fully unbundled and shared access lines) compiled by the European Commission and evaluated their association with per capita investment levels and the indicators of market competition for the EU27. Correlations between both de facto price indicators and market shares were not statistically significant and are not reported here. This observation represents a puzzle for the usual price theoretical model of regulation and entry, which suggests lower regulated prices should lead to more entry. However, this may be simply a function of the divergent paths in the co-evolution of regulation and telecom market competition across old/new EU member states as noted above. The price of shared access also shows little association with per capita investments in network infrastructure subsequent to the financial crisis of the late 2000s.

The price of fully unbundled loops has a significant positive association with the level of capital expenditures and with the diffusion of non-DSL technologies (i.e. inter-platform competition). This observation may seem intuitive in the context of the usual economic model emphasizing the tradeoffs between static and dynamic efficiencies: If operators of existing facilities (i.e. last mile/km links and local switching facilities) can charge more for access to such network fixtures, they may have stronger incentives to invest in such specific assets. Importantly however, the empirical association between the price of fully unbundled loops and per capita investment levels in fixed network assets becomes very weak once we control for cross-country cost differences in deploying network infrastructure with the urbanization rate (statistically significant only at less than a 10% significance level). Since the costs of network provision are an integral part of calculating regulated prices by the national regulators, this is not necessarily surprising.

One potential reason for previous difficulties in finding an empirical link between existing cross-country indicators of regulation and network infrastructure development might be the fact that institutional differences that matter are much more subtle. For example, even when the law requires third party access and the prices seem reasonable, entities who do not want to cooperate with more efficient competitors can engage in delaying tactics, legal intransigence, and increase the costs of entry. Differences in corporate cultures that shape the tendency of the firms to cooperate with third parties and escalate disputes to regulators are also likely to be important for explaining how public policy influences network outcomes. As far as we are aware, there are no reliable indicators of informal barriers to accessing facilities that regulatory authorities have deemed to be essential or differences in the managerial behavior/ability of operators. Subjective indicators of regulatory quality such as the one from ECTA detailed above may capture some of the more subtle aspects of institutional environments, but they are also not very reliable because they reflect perceptions of those with an interest in the design of the regulatory system. In addition to the obvious arbitrariness in weights used to add individual dimensions of complex regulatory systems into simple indices such as Polynomics and TRGI, the example of empirical literature on regulation and investment in EU telecoms suggests that policy implications of particular studies tend to depend on the construction of windows/metrics employed to capture regulatory variation across jurisdictions.

A number of recent studies have outlined other problems with the data and methodology of the literature on regulation and investment in European telecoms. Bacache et al. (2013) point out that value of fixed assets of firms employed by Grajek and Roller (2012) does not directly capture network investments as it does not distinguish between capital expenditures in network facilities and other forms of investment.[9] For a more direct measure of capital expenditures Bacache et al. (2013) instead employ data on the number of new broadband, local loops, and bitstream access lines of entrants to evaluate the relevance of the "ladder of investment" hypothesis. They find some support that new entrants invest in infrastructure, but show that their incentives to invest in the last mile have been limited. They do not find a statistically significant association between the Polynomics regulatory intensity index and their more direct indicators of capital expenditures by entrants. While their analysis is particularly relevant for highlighting natural monopoly tendencies on the edge of Internet access networks and challenges facing potential entrants, the number of particular types of lines remains an input into the network development process.

Briglauer et al. (2013) explore the traditional hypothesis about the existence of a trade off between static and dynamic efficiencies in terms of the diffusion of next generation fiber broadband networks in Europe. In contrast to Bacache et al. (2013) who use the number of new lines as a measure of capital inputs, Briglauer et al. (2013) employ a technical measure of the allocation of network connections between different classes of market participants as a proxy for regulation (% of regulated wholesale lines to total retail broadband lines). As their dependent variable, they use the number of homes passed by fiber-to-the-node/premises (FTTx) technologies. They find a statistically significant negative correlation between their implicit indicator of regulation (relative size of the wholesale market) and the diffusion of NGNs in the EU. They take this observation to extend the policy lesson from the standard model about the likelihood of cost-based regulation of access to essential facilities in emerging platforms (i.e. fiber) reducing their diffusion in the future. This analysis provides some support for the idea that increasing the authority of the European Commission to enforce essential facilities obligations on providers of high-capacity fiber access and transport networks may not be beneficial to all members. It is precisely this question that lies at the core of debates about the scope of legal authority to regulate interconnection to the Internet that member states are willing to grant to EU institutions (Ruhle and Reichl, 2009; Simpson, 2011; Montolio and Trillas, 2013).

[9] Unless they have been forced by some form of vertical/accounting separation directive, operators do not usually publish this data. While there are ongoing efforts at the ITU and EU to motivate national telecom authorities to collect information from operators that segment investments in fixed broadband, mobile, and other network facilities, these efforts have not yet been successful. In addition to the strategic value of this information, one reason for this might be that convergence of these platforms makes it increasingly difficult for the operators themselves to segment the numbers from an accounting perspective.

Bauer and Shim (2012) study overall broadband penetration and the number of secure servers in particular countries as indicators of innovations in digital infrastructure development. They employ the Polynomics regulatory intensity index to capture national policy differences and find a negative relationship between this indicator and both measures of innovation/market outcomes. This negative sign is consistent with our empirical results based on the Polynomics regulatory intensity/density index and presented in Table 2 above. However, in our specification regulatory intensity only has a statistically significant effect on short term investment growth rates (Model B, Table 2), but the negative sign on per capita investment levels for the EU27 is statistically insignificant. This is consistent with the observation by Bauer and Shim (2012) that the results of empirical models in this area depend on the models' exact specifications. The critical review of the empirical literature in this section confirms this perspective on the problem and suggests the importance of simplicity in empirical models.

4. Determinants of broadband infrastructure quality

Policy debates about the optimal design of access to network facilities considered essential (i.e. natural monopoly components) described above are invariably situated within the structure of the traditional model of tradeoffs between static (i.e. market power) and dynamic (i.e. investment incentives) efficiencies. While the regulated monopoly model for the governance of telephone companies collapsed long ago, the continued focus of policymakers on fixed capital expenditure represents a relic of that history. From a public policy perspective investment incentives of those who operate large and complex communication networks are clearly relevant when the public sector is subsidizing the private efforts or is somehow responsible for the financial obligations of the operators. As privatization and deregulation have removed financial risks from the public sector, policymakers have become more interested in more direct measures of infrastructure quality outcomes (i.e. broadband availability, price, quality of service). Investments in monetary terms or captured as the quantity of particular types of lines/technologies represent one of the many inputs that ultimately shape the quality of the network that is made available to end users of the system.

The obvious measure of network outcomes that remains relevant in developing countries is the availability of high-speed networks to the population. In advanced economies questions of geographic coverage of 1st generation broadband have been, more or less, resolved.[10] With near ubiquitous coverage, policy attention is increasingly shifting to operators' incentives to deploy more advanced/high speed platform technologies required for the widespread diffusion of 2nd generation/resource intensive Internet content and application services (Ezell et al., 2009). Various governments have started to pay more attention to the relevance of broadband speed measurements as policy outcomes, while others have been more active and deployed purpose built test-beds to benchmark and monitor differences between advertised and actual service quality (e.g. SamKnows projects in EU, U.S., U.K.).[11] Given the importance of connection quality/speed to the delivery of 2nd generation Internet applications, various content and application companies also collect and disseminate information about service quality (e.g. Google, Netflix).[12]

There are well-known differences between the magnitude of broadband speed measurements across different classes of testing methodologies, a review of which is beyond the scope of this paper. The reader may turn to Bauer et al. (2010) for an insightful analysis. The rest of this section extends the debates about the interplay between regulation, investment, and network development using measurements of broadband connectivity speeds from Akamai Technologies (2013). Akamai's Content Delivery Network (CDN) is relatively large (carrying around 30% of Internet traffic) and provides an empirical basis for capturing the service quality end users experience when deploying more advanced/2nd generation applications and content services. Data from Akamai is also useful because it allows us to study cross-country variations in network quality in both congested and non-congested states of the system (i.e. late afternoons and evenings when everybody wants to use the Internet, versus after midnight; see Bauer et al., 2012).

As noted in the introductory sections to this article (Figs. 1 and 2), EU members with a higher degree of competition (service-based or inter-platform) appear to have developed relatively high capacity networks. This observation stands in sharp contrast to the literature on regulation and investment in the EU outlined in the previous section which suggests more competition may not be good for network development (i.e. due to lower investment incentives for incumbents). If efficiency gains from competition and market discipline are strong enough, policies that promote competition may reduce investment levels and enhance infrastructure quality simultaneously.

4.1. Capital allocation and technological change

Previous qualitative studies using broadband speed measurements suggest countries with strong open access policies have developed relatively high quality broadband networks (Berkman Center for Internet, 2010). There are few quantitative studies that explore the determinants of broadband infrastructure outcomes in terms of the quality of Internet connectivity end users experience on shared network infrastructure. Focusing on a sample of OECD countries, Rajabiun and

[10] The exception is provision of access to rural and remote areas. See OECD Broadband Statistics, Tables 3d–g. Available at: <http://www.oecd.org/sti/broadband/oecdbroadbandportal.htm>.

[11] <https://www.samknows.com/>.

[12] <https://www.google.com/get/videoqualityreport/>; <http://ispspeedindex.netflix.com/>.

Table 4
Investment patterns and network outcomes.

	AvgG	PeakG	AvgS12	PeakS12
InvG	−0.28	**−0.36**	0.12	−0.05
RevG	**−0.35**	**−0.40**	−0.10	−0.10
Inv/Rev	0.13	**0.25**	0.02	0.13
InvL	−0.23	**−0.32**	−0.05	**−0.41**
NGN	−0.05	0.03	**0.34**	**0.63**
Non-DSL	0.08	0.21	**0.44**	**0.64**

Middleton (2013b) found that the penetration of non-DSL platforms has a strong positive association with the quality of Internet connectivity in terms of average speeds end users can achieve, while quality uncertainty in the past has a significant negative effect on future performance (i.e. the Lemons Problem). They employ TRGI to control for regulatory and income variations, but do not find an empirical link between this indicator and broadband speed measurements for OECD countries.

The review of quantitative literature in the previous section indicates that the sign and magnitude of correlations between policy indicators and capital inputs can depend on the exact specification of the empirical model. Our analysis of available metrics employed in previous studies further highlighted that these effects also depend very much on the construction of the relevant indicators of cross-country variation in the regulatory environment. These considerations further highlight the importance of moving from simple to more complex models for evaluating the determinants of broadband infrastructure quality and employing market outcome variables that capture the reality of Internet connectivity from the perspective of end users (versus financial accounting or technological indicators of inputs into the system).

In the analysis that follows our dependent variables are average and peak network speeds, as well as their growth rates between 2007 and 2012. Average speeds reflect the state of connectivity when most people want to use the Internet and capture the ability of operators to meet growing demand for network resources at times of the day when most end users want to deploy increasingly resource intensive applications. In contrast, peak measures reflect average maximum network speed detected by Akamai's global system of servers (i.e. when demand is low; after midnight). The gap in broadband network performance in high/low traffic states has grown substantially since the late 2000s, indicative of rapid growth in demand for network resources, congestion and well-known concerns about traffic shaping/throttling/network neutrality. In other words, as demand for network resources has grown due to the diffusion of 2nd generation applications, operators have had to install relatively more excess capacity to avoid degradation in service quality associated with congestion on local links and switching facilities. Our explanatory variables include indicators of per capita investment levels, their growth, inter-platform and service-based competition, NGN diffusion, and regulation. The Appendix describes the variables and their sources. Table 4 presents correlations among the variables that help explore if there is indeed any empirical association between investment inputs and the quality of Internet connectivity.

There appears to be a dichotomy in the direction of associations between investments and network outcomes, depending on the type of indicator we employ to capture capital inputs. There is a negative correlation between the level of per capita investments (InvL) and measures of network performance (AvgS12, PeakS12) and its growth over time (AvgG, PeakG). Average and peak speeds of Internet connectivity further appear to have grown relatively slowly in countries with higher rates of investment and revenue growth. Nevertheless, this negative correlation is only significant with respect to peak speed measurements at the end of the period and becomes both insignificant and negligible in magnitude once we control for cost differences with the urbanization rate. Consequently, per capita investment levels appear to have little power in explaining cross-country differences in broadband network infrastructure quality in the EU. This sheds some doubt on the relevance of studies that employ monetary indicators of capital input levels to evaluate the interplay between public policy and broadband infrastructure development. If efficiency gains from more competitive discipline, less duplication, and/or better management practices are sufficiently high, there is no reason to expect that countries with relatively higher levels of aggregate capital expenditures would develop relatively high quality networks.

Table 5
Inter-platform competition and network quality.

	Coef.	*p*-Value		Coef.	*p*-Value
Intercept	17.446	0.010	Intercept	23.977	0.000
UrbanR	−0.027	0.732	UrbanR	−0.089	0.230
UseR	0.060	0.498	UseR	0.056	0.524
Non-DSL	**0.150*****	0.001	NGN	**0.201*****	0.001

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

To see why this might be the case, consider capital expenditures as measured in terms of their quality (i.e. share of the market by more advanced technologies linking end users to the Internet; non-DSL, NGN). There is a positive association between the diffusion of more advanced broadband platforms with indicators of both average and peak network performance. The positive link is particularly strong on peak measured speeds, which can be viewed as an indicator of network capacity operators have installed to limit service quality degradation in high traffic periods. Starting from the simplest possible linear regression model, we control for differences in the costs of deploying networks with the urbanization rate and the proportion of the population that uses relatively network intensive applications (watching TV on the Internet, downloading music, etc.). Suppose cross-country differences in the quality of Internet connectivity are a function of variation in three sets of factors: (a) Past capital inputs, (b) The costs of upgrading/deploying networks, and (c) Demand for network resources. As documented in Table 5, the positive impact of the two indicators of technological quality of investments on peak quality/capacity remains statistically relevant even after controlling for cost differences and demand side variability. In fact, the usual controls do not appear to matter very much in the context of the strong effect of technological change/ inter-platform competition on network quality. In terms of magnitude, on average a 1% increase in the penetration of non-DSL and NGN technologies is associated with an increase of .15–.2 Mbps in terms of peak network quality/capacity.

The absence of significant association between our control for demand intensity and peak performance is not surprising. Since this speed indicator reflects network quality when the load on the system is low and not too many end users want to use the network, it already controls for variations in demand patterns across the sample. The fact that the urbanization rate is not associated with connectivity speeds is more surprising because in more densely populated areas the fixed costs of upgrading/deploying network capacity can be spread across a large number of subscribers. We therefore cannot reject the null hypothesis that at least this class of costs have little to do with variations in broadband infrastructure quality in the EU. This suggests other factors such as public policy, firm strategies, and catch-up processes might be more important for explaining cross-country differences in broadband infrastructure quality. Differences in the diffusion of non-DSL and NGN platforms appear to "explain" less than 40% of observed variations in the quality of Internet connectivity in the EU.

4.2. Regulation, competition, and other determinants of network development

The discussion in the previous sections suggests more competition may be negatively associated with the level of capital expenditures on telecom infrastructure, but the level of investments do not necessarily explain cross-country differences in broadband network development. This section presents the results of our search for other factors that may have influenced the capacity of operators to meet growing demand for network resources based on various indicators of regulation, competition, and other features of the market detailed in the previous sections and listed in the Appendix to this article. Starting with this set of variables we have eliminated those with little explanatory power, as well as those that are highly correlated and may pose multi-collinearity issues. For example, countries where entrants have a larger share of the market also tend to have higher rates of non-DSL/NGN diffusion. It would therefore be inappropriate to employ both market share and technology diffusion rate indicators in a regression as it would lead to a double counting. Table 6 presents the results of a number of regressions aimed at decomposing different classes of factors that can help explain observed variations in Internet infrastructure quality. Only the regressions with respect to peak speeds and their growth are statistically valid (at 5%), which is not surprising as peak performance measures already control for variations in demand by capturing network quality at the low-load state of the system. Nevertheless, we also present the results with respect to average network quality for comparison.

The speed of Internet connectivity over short periods of time can vary significantly, depending on investments by operators in network resources in the past and current demand by other end users in the vicinity that share the infrastructure. Even after averaging the average speeds over a number of quarters, explaining them at this level of aggregation seems difficult and will require future research attention. The only variable that seems to be important for explaining differences in both average and peak speeds is the entrants' share of the market. Controlling for various policy and financial indicators, by 2012 EU members with a relatively higher degree of service-based competition had developed relatively high

Table 6
Determinants of broadband infrastructure quality.

Y	AvgS		PeakS		Avg. Growth		Peak Growth	
	Coef.	*p*-Value	Coef.	*p*-Value	Coef.	*p*-Value	Coef.	*p*-Value
Intercept	2.762	0.441	10.668	0.344	31.834	0.240	54.958	0.322
InvL	0.005	0.668	−0.036	0.296	**−0.215****	0.014	**−0.494*****	0.007
EntrantS	**0.057***	0.065	**0.237****	0.018	**−0.531****	0.025	**−0.912***	0.057
Full LLU	−0.158	0.344	−0.659	0.213	0.116	0.925	−0.382	0.881
RegInt07	−0.063	0.360	−0.212	0.325	0.041	0.935	0.302	0.773
Inv/Rev	0.002	0.985	0.385	0.152	**1.174***	0.072	**3.656*****	0.009
TRGI	0.062	0.159	**0.241***	0.083	0.290	0.368	0.665	0.318

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

quality broadband networks. The positive impact of service-based competition on network quality is substantially stronger in terms of statistical significance and magnitude on our outcome variable peak speeds (PeakS) than the effect on average speeds (AvgS). The average price of unbundled loops and regulatory intensity are not significant in any of the regressions. This stands in contrast to the positive effect of the broad TRGI measure of regulatory variation, which is statistically significant at the 5% level with respect to our peak speed variable. Regulatory intensity as measured by the Polynomics index appears to have little to do with network development, which is consistent with results of Bacache et al. (2013) detailed earlier.

Both average connectivity speeds and peak network capacity appear to have grown more slowly in countries where investment levels were higher and incumbents faced more competition. In other words, the physical capacity of broadband networks increased faster in countries that had relatively lower levels of investment and service-based competition. This might seem counterintuitive in the context of the usual policy model of regulation, competition, and investment, but it may be simply a function of different paths in the co-evolution of regulation, entry, and investment in different regions of the EU as outlined in the preceding sections. The most important determinant of network quality improvement over time appears to be the level of investment by firms as a proportion of their revenues (Inv/Rev). The magnitude of the positive impact of this financial variable is particularly strong on the growth in peak network quality/capacity rates between 2007 and 2012. Where operators reinvested a larger proportion of their revenues in future capacity growth (versus holding the cash or paying the investors), the pace of progress in network quality improvements was higher. Furthermore, the magnitude of this positive effect is between 3 and 7 times larger than the negative coefficients of per capita investment levels and entry on the rate of network capacity/quality enhancements.

The determinants and impact of financial strategies by operators on broadband infrastructure development have not been previously studied and it is beyond the scope of this paper to explore them further. Nevertheless, it is relatively easy to understand the result with respect to the investment/revenue ratio in terms of the empirical puzzle outlined in this paper. In a world of global finance where large investors can adjust their portfolios, less efficient/more risky firms will have to pay more for external capital. Consequently, they will have less to reinvest in network capacity upgrades and next generation platforms as they have to allocate a larger proportion of their revenues to satisfy risk averse investors. It is precisely these firms that have incentives to warn policymakers about the potential for "under-investment" and the need for policies that promote their investment incentives.

5. Summary and implications for multilevel governance in the EU

Under the regulated monopoly model for financing and governing organizations that operated copper telephone networks, policymakers were ultimately responsible for the outcomes in terms of access to and quality of the communication system. Even though this era has passed and private sector innovation has been the key driver of Internet infrastructure development, the traditional policy model from that era remains pervasive in debates about the design of telecommunications policy in the transition to Next Generation Networks (NGNs) and interconnection/essential facilities access regulations. This article provides an empirical critique of the traditional model that assumes the existence of a tradeoff between static (i.e. market power) and dynamic (i.e. investment incentives) efficiencies in the co-evolution of public policy and broadband connectivity. The first part of the article described the contradictory results of previous literature and characterized the working hypothesis: Relatively weak regulatory obligations to interconnect with third parties that want to access essential facilities may help promote capital expenditure levels, but higher investments do not always translate into higher network quality (presumably due to some efficiency loss or duplication).

Section 3 provided a critical review of empirical literature on access regulation, competition, and investment in the European Union. Using a variety of indicators of regulation and telecom policy employed in the debates, the analysis illustrated that the direction of association between the design of the regulatory institutions and investment levels in telecoms depends very much on the construction of indicators for capturing policy variation across jurisdictions. Updating previous results by Cadman (2007), we confirmed the presence of a positive correlation between perceptions-based indicators of regulatory quality and capital expenditures in fixed network assets in the EU. However, we also showed that this link is statistically weak and reflects the fact that (both sector specific and general) perceptions-based indicators of regulatory quality tend to rank Western/Northern European countries relatively higher than Southern/Eastern members. Furthermore, as in Grajek and Roller (2012) we found a negative association between measures of the density/intensity of regulatory obligations on incumbents and capital expenditure levels; but show this empirical link becomes tenuous once we control for differences in network deployment costs with the degree of urbanization. The negative association between the level of competition by non-incumbents and investment levels remains robust when including controls for supply, demand, and various indicators of regulatory variation across EU members.

These somewhat contradictory observations can be interpreted in the context of divergent paths of regulation, technological change, and network development within the EU. In accession countries that had to adopt relatively more credible implementations of the EU policy framework and open access rules in the early to mid 2000s, incumbents were relatively more constrained in their ability to engage in anticompetitive practices and deter entry. This helped increase the pace of transition from sunset copper/DSL platforms to more advanced technologies (i.e. non-DSL/NGN) relative to non-accession/incumbent EU member states where entrants' share of the market has remained relatively low. Importantly, it is precisely

these incumbent EU member countries that have relatively low levels of non-DSL platform diffusion and higher per capita capital expenditure levels.

Section 4 extended the discussion by pointing out that capital expenditures represent only one of the many inputs into the process of network development. We instead use broadband speed measurements between 2007 and 2012 to construct network outcome indicators that capture the quality of end users' Internet connectivity experiences and study their determinants. We find little evidence to support the hypothesis that higher capital expenditure levels lead to higher network quality. To the contrary we observe a statistically significant negative association between the level of capital expenditures and broadband connectivity speeds: On average, countries with relatively lower investment levels have more service-based competition, have developed relatively higher quality networks, and are further along in the transition from DSL-based connectivity to next generation fiber platforms. Differences in network quality/speeds across the EU appear to be driven primarily by the extent of the diffusion of non-DSL/next generation platforms, competition in the provision of Internet access services, and the proportion of their revenues operators reinvest in fixed network infrastructure.

In terms of designing regulations for the governance of the wholesale Internet access markets, the implications of this analysis stand in some contrast to the prescriptions of previous studies that focus primarily on the potentially negative impact of access obligations on operators' incentives to invest in fixed network infrastructure (e.g. Grajek and Roller, 2012). This class of studies typically assumes that capital expenditures represent the key measure policymakers should be concerned about and takes the negative link between service competition and investment to imply that access obligations should be minimized in order to maximize irreversible capital expenditures. However, investment is only one input into the process of increasing network capacity and deploying new technologies in response to growing demand for high-speed Internet connectivity. If there is over-investment in sunset broadband platforms (i.e. DSL), too much duplication of essential network facilities, or a lack of competitive discipline on dominant operators, there is no reason to expect that countries with relatively high levels of capital expenditures will develop relatively high quality broadband networks. The EU experiences detailed in this article suggests end users in countries that have been more effective in encouraging entry tend to experience relatively higher connectivity speeds and have more access to advanced broadband connectivity platforms. Evidence from the EU lends further support to and helps explain a second class of previous studies that suggest open access regulations which promote service-based competition are conducive to the emergence of relatively high quality broadband networks (Berkman Center for Internet, 2010; Choi, 2011).

Beyond this general implication for regulatory policy design, the analysis of differences and determinants of network quality in the EU provided here appears particularly relevant in the context of debates about the allocation of telecom policy authority within the Union's multilevel system of governance, progress towards EU's broadband speed targets (i.e. 30 Mbps), and attempts to build a single European telecom market through regulatory harmonization. Concerns about the quality of Internet connectivity and access to essential facilities in some EU member states provide the impetus for ongoing debates about the scope of European Commission's authority to regulate telecommunications (Ruhle and Reichl, 2009; Simpson, 2011; Montolio and Trillas, 2013). Countries that have already managed to develop local regulatory regimes that are effective in supporting broadband infrastructure development would clearly have little incentive to relinquish their authority over access regulation to EU institutions and become exposed to the risks of unfavourable central policies or regulatory capture at the center. In contrast, where local incumbents and local regulators have a close working relationship which appears to stifle competition, innovation, and technological change, moving away from local regulatory authority may help promote the pace of progress toward next generation connectivity. Broadband infrastructure policy in the EU and debates about the allocation of regulatory authority over essential facilities access and interconnection represent another manifestation of broader challenges associated with procedural regulatory autonomy in increasingly integrated markets. Reducing the scope for national regulators to interpret EU level obligations and increasing oversight by the Commission may encourage improved outcomes in some EU members where there has been relatively little effort to enable access to new entrants and/or promote the diffusion of more advanced broadband technologies. In countries where national regulatory regimes have been relatively effective in fostering competition and technological change, a shift to an EU-wide system with one set of rules for the governance of a single market can limit the flexibility of local policymakers to adopt institutional arrangements that reflect local demands and market conditions.

Acknowledgements

We would like to thank Akamai Technologies, Polynomics AG, and Pantelis Koutroumpis for providing their data. This research was undertaken, in part, thanks to funding from the Canada Research Chairs program and was supported by the Social Sciences and Humanities Research Council (Canada), the GRAND NCE and Ryerson University.

Appendix A. Description of variables and sources

Variable	Unit	Description	Source
AvgS	Mbps	Average connection speed per unique IP address, averaged over the first three quarters in 2012 to control for seasonality	Akamai Technologies
PeakS	Mbps	Maximum connection speed per unique IP address, averaged over the first three quarters in 2012	Akamai Technologies
AvgG	%	Average annual growth in average broadband speeds between 2007 and 2012	Akamai Technologies
PeakG	%	Average annual growth in peak/maximum connection speeds between 2007 and 2012	Akamai Technologies
InvL	Euro	Average annual per capita fixed capital expenditures in telecom network infrastructure between 2009 and 2011	EC Digital Agenda Data Portal
InvG	%	Growth in telecom capital expenditures; 2010–2011	EC Digital Agenda Data Portal
RevG	%	Growth in telecommunications revenues (2010–2011)	EC Digital Agenda Data Portal
Inv/Rev	%	Capital expenditures as a proportion of revenues	EC Digital Agenda Data Portal
EntrantS	%	Non-incumbent operators' share of the broadband market	EC Digital Agenda Data Portal
non-DSL	%	Share of non-DSL (i.e. cable + fiber + other) in the broadband market	EC Digital Agenda Data Portal
NGN	%	Penetration of next generation technologies as a percentage of total	EC Digital Agenda Data Portal
Full LLU	Euro	Average price for a fully unbundled loop	EC Digital Agenda Data Portal
UseR	%	Proportion of the population using the Internet to watch TV, download movies, music, etc (i.e. network intensive content applications)	EC Digital Agenda Data Portal
UrbanR	%	Percentage of population living in urban areas	CIA World Factbook
ECTA	(0–100)	Perceived Regulatory Quality	European Competitive Telecommunications Association
RegInt	(0–100)	Index of intensity/density of telecom regulations	Polynomics AG
Poltrans	(0–100)	General index of political transparency	Transparency International/ Waverman and Koutroumpis (2011)
Regtrans	(0–100)	Index of telecom regulatory transparency	Waverman and Koutroumpis (2011)
RegInd	(0–100)	Index of telecom regulatory independence	Waverman and Koutroumpis (2011)
RegRes	(0–100)	Index of resource available for telecom regulation	Waverman and Koutroumpis (2011)
Enforc	(0–100)	Index of enforcement of telecom regulations	Waverman and Koutroumpis (2011)
TRGI	(0–100)	Telecom Regulatory Governance Index	Waverman and Koutroumpis (2011)

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