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

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Regulation, Investment and Efficiency in the Transition to Next Generation Networks: Evidence from the European Union

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Abstract

This article explores the impact of public policy, technological change, and the development of Internet connectivity in EU members. The analysis illustrates that the results of previous empirical literature on the interplay between regulation, competition, and investment depend on the construction of indicators employed to evaluate this interaction. Furthermore, the article points out that the traditional policy model and related empirical literature treats fixed capital inputs in networks as a measure of digital infrastructure quality/outcomes. Using broadband speed measurements between 2007 and 2012, the article addresses this gap in the literature and evaluates the determinants of digital infrastructure quality in the EU. The analysis suggests the primary driver of network quality in the medium to long term is the willingness and/or ability of operators to reinvest more of their revenues in network capacity improvements.

Keywords

Broadband Networks, European Union, Regulation, Technological Change, Federalism

1. Introduction

This article investigates the relationship between public regulation and the development of broadband Internet connectivity in member states of the European Union. Understanding this link is important because of the potential for private sector under-investment in capacity upgrade and the adoption of 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 & Silvestri, 2012; Krämer, &

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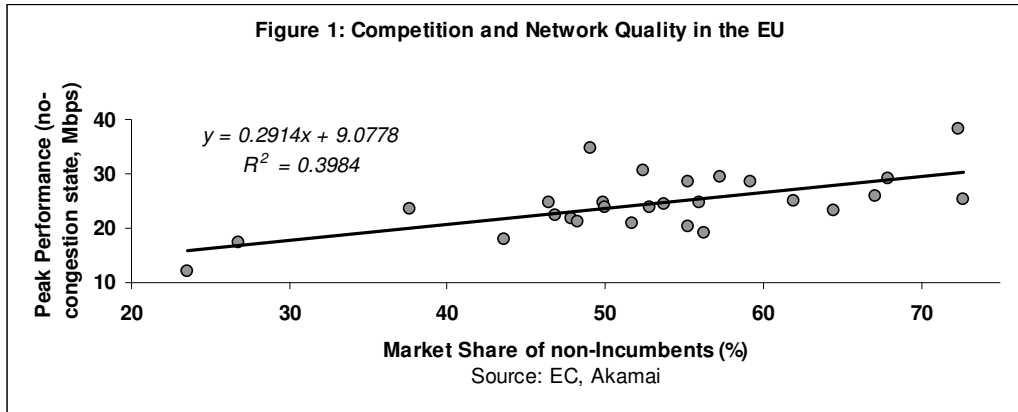
Vogelsang, 2012). This article asks if and how regulatory diversity in the member states can explain differences in the development of broadband Internet connectivity in the EU.

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 relatively restrictive regulatory obligations on facilities operators requiring them to interconnect with third parties are negatively correlated with capital expenditures on fixed assets at the national level and by incumbent network operators (Grajek & Roller, 2012). This observation is important from a policy perspective because inter-platform competition 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 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 have developed higher quality broadband systems (Berkman Center, 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 would also help explain why countries with relatively high capital expenditures on telecoms do not necessarily have relatively high quality network infrastructure (Rajabiun & Middleton, 2013a). This article will explore the broader empirical puzzle suggested by recent cross-country studies 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 policies that might be necessary for overcoming the under-investment problem in the future 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 outcomes, especially in maturing markets where near universal access to first 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, 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 map them into capacity upgrades and new technologies. These include firm specific internal factors (e.g. managerial efficiency and technical skills), as well as external competitive discipline on

network providers and their employees. As Figure 1 illustrates, the recent experience in EU member states lends some support to this hypothesis.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, investments in more advanced broadband platforms, and the quality of Internet connectivity end users experience. Section 4 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.

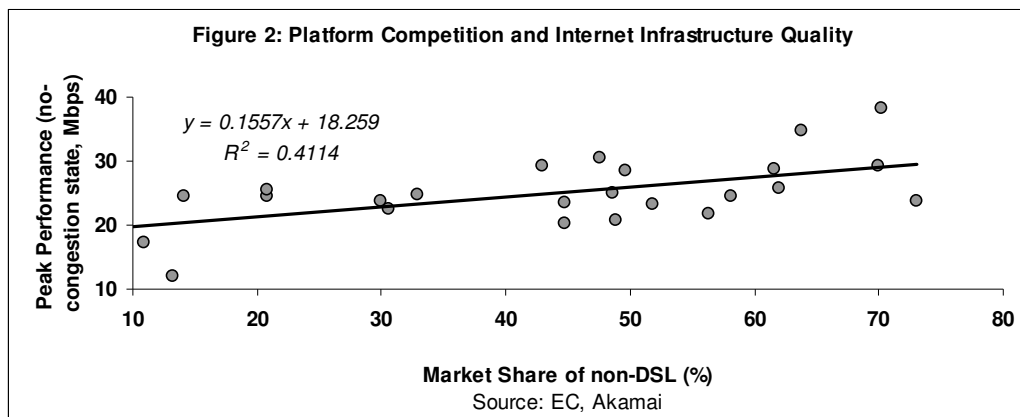
2. Motivation: Competition, Regulation, and Efficiency of Network Investments

As technological innovation made it more difficult to sustain the traditional regulated monopoly model in telecommunication, by the late 1990s and early 2000s most advanced economies adopted broadly similar policy strategies to shape digital infrastructure development. 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 telephone networks to unbundle their local loops and provide potential third party entities access to particular components of the network deemed essential by the policymakers. 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 the two countries have been relatively reluctant to employ their statutory authority to compel platform operators to interconnect with third parties (i.e. regulatory forbearance). In Japan and Korea

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

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 digital 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 & Pelkmans, 1995; Lehr & 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 and the reader can turn to Cambini & Jiang, (2009), Bauer (2010) and Belloc et al. (2012) for insightful overviews. While evidence on the interplay between regulation and investment is mixed (Cambini & 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 Figure 1, countries with a higher degree of service-based competition in the EU also appear to have developed relatively high-capacity broadband systems. In addition to the empirical importance of service based competition to digital infrastructure quality, previous international studies further document penetration growth and network quality/speeds tend to be higher in countries with a higher degree of inter-platform competition (Ware & Dippon, 2010; Bouckaert et al., 2010; Rajabiun & Middleton, 2013b). Figure 2 illustrates that a positive association between platform competition and network quality has also characterized the recent experience in EU member states (i.e. EU27).²



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

The fact that both service and platform based competition appear to have a positive association with economic incentives to deliver high quality Internet connectivity provides a basis for understanding the basic dilemma in the design of essential facilities/interconnection regulations facing policymakers. Economic theories of telecommunications suggest that in the short run policymakers can improve economic efficiency by imposing more onerous 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 (Laffont & Tirole, 2000; Kotakorpi, 2006).

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 map 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 ability and 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).

From a theoretical perspective, if the magnitude of the efficiency loss from a lack of market discipline and/or poor management is sufficiently large, it is possible to imagine how the well-known theoretical tradeoff between static (i.e. market power/consumer welfare) and dynamic efficiency (i.e. investment incentives) can vanish. 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 (i.e. too much waste and/or duplication). Section 4 will explore this null hypothesis based on measurements that capture the quality of Internet 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 in the late 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 member states to implement open access regulations and limit the exclusionary tendencies of incumbent operators. Incumbent 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 & 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 & Reichl, 2009; Simpson, 2011; Montolio & 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 EU policy framework and essential facilities obligations prior to the first round of expansion in 2004, potential entrants into EU markets 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) to capture the quality of national regulatory regimes (ECTA Regulatory Scorecard). Cadman (2007) showed the existence of a significant positive association between ECTA's perceptions based Scorecard and per capita investment levels in 16 EU countries in 2003-2005. The ECTA Scorecard is compiled from surveys of ECTA membership, which includes primarily non-incumbent operators 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. 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).³

In Table 1 we investigate if the positive association between ECTA's indicator of regulation 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

³ 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>

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 short term investment growth patterns. 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 on EU members (i.e. Western/Central versus Southern Europe).

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

The negative association between entrants' share of the broadband Internet market (EntrantS) and capital expenditure levels (InvL) on fixed assets 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. Although both regressions are significant and explain around 50 to 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).⁴ 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 digital infrastructure quality in incumbent/non-accession EU members grew, they started to invest more.

⁴ 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-collinearity in the regressions.

- 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 each other 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 is likely to matter more than their capacity to promote business cooperation over access to essential facilities/interconnection. One such a measure (Plaut Economics Regulation Index and its updated version, the Polynomics Regulation Index (2012)) has been employed in a series of studies that challenge the hypothesis about the positive link between open access regulations and digital infrastructure investments (Zenhäusern et al., 2007; Grajek & Roller, 2012; Bacache et al., 2013). Grajek & Roller (2012) look at industry and firm level capital expenditure in the EU over a 10 year period and find a negative association between regulatory intensity/density and investment. They also find that access regulation is not associated with investment levels of entrants, but reduces capital expenditures by incumbents.⁵

Table 2 provides the results of our assessment of the association between regulatory intensity as measured by the Polynomics Index and investment in the EU 27 following the financial shock of the late 2000s. While there is a negative correlation between regulatory intensity and the level of subsequent capital expenditures, 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 rates of growth in investments (Model B). This suggests investments recovered faster from the crisis in countries with relatively simple rules (versus complex standards).⁶

Overall, these empirical models explain a smaller proportion of subsequent variation in per capita investments and capital expenditure growth than those using perceptions of regulatory quality measures 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

⁵ 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.

⁶ See Christensen 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.

based and platform competition, but did not find a statistically relevant association and do not report the results.

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

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. In Table 3 documents correlations among various lagged institutional indicators (circa late 2000s) and measures of capital expenditures in the subsequent years in the EU (2009-2012).

**Table 3. Institutional Differences and Investment Patterns
EU27**

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

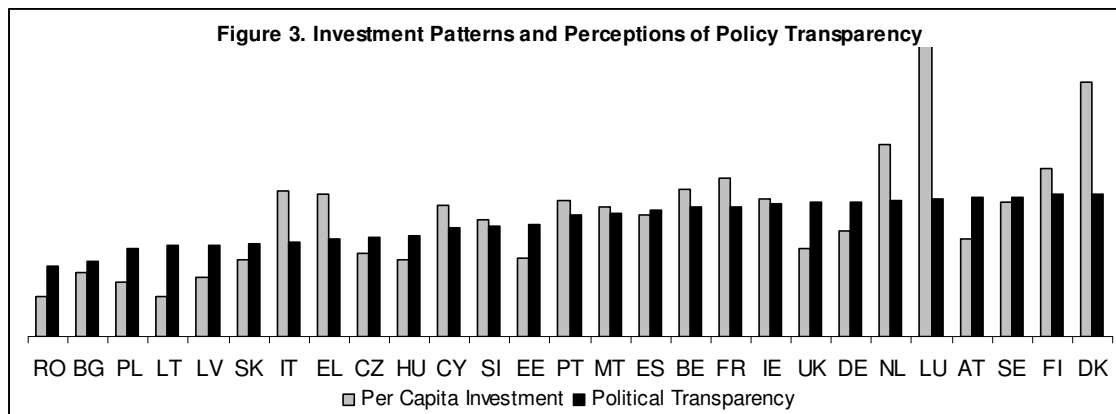
This overview of the interplay between institutional variation, nominal investment levels, and technological outcomes in the EU helps highlight the relevance of the empirical puzzle set out in this article, which may help move beyond the traditional model of tradeoffs among static and dynamic efficiencies. 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 indicators 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 on in terms of the broad measure of perceived political transparency/accountability/anti-corruption, as compiled 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, 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 platform competition remain 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 EU expansion process, increasing role of European institutions in telecommunications regulations, and 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 the 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 financial crisis (see Figure 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 vertical 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 vertical 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 interconnect 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. 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/kilometer 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 differences of 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/escalate dispute 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 perspectives that explore differences in 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 EU telecoms suggests that the origins of particular windows/metrics into the world of policy helps predict policy implications that emerge from studies that employ that particular lens to capture regulatory variation.

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 & Roller (2012) does not directly capture network investments as it does not distinguish between capital expenditures in network facilities and other forms of investment.⁷ 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 so-called “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. (2012) 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. (2012) employ a technical measure of the allocation of network connection 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 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 & Reichl, 2009; Simpson, 2011; Montolio & Trillas, 2013).

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

⁷ 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.

empirical models based on this 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. For example Bauer and Shim (2012) explore potential for non-linearity in their models by taking logs of the variables, which makes it difficult for them to identify the strong negative relationship between the level of entry by non-incumbents for broadband access services and per capita investments levels in Tables 2 & 3 above (even after controlling for either ECTA or Polynomials indicators of regulatory quality and intensity respectively, as well as variations in supply/cost and demand side conditions at the national level).

4. Determinants of Digital 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 represent 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. access, 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 network development.

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 (i.e. DSL) have been resolved⁸ and 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.). Given the importance of connection quality/speed to the delivery of 2nd generation Internet

⁸ The exception is provision of access to rural and remote areas, which are generally not served by fixed line infrastructure.

applications, various content and application companies also collect and disseminate information about service quality (e.g. Google, Netflix).

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 and 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. Akamai's Content Delivery Network (CDN) is relatively large (carries 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 above (Figures 1 & 2), EU member with a higher degree of service and platform competition appear to have developed relatively high capacity networks. This observation stands in sharp contrast to the results of 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. lower investment incentives of 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 more credible open access policies have developed relatively high quality broadband networks (Berkman Center, 2010). There are few quantitative studies that explore the determinants of digital infrastructure outcomes in terms of the quality of Internet connectivity end users experience on shared network infrastructure. Focusing on a sample of OECD countries, Rajabian and Middleton (2013b) have 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 last 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 digital infrastructure quality based on metrics that capture the reality of Internet connectivity from the

perspective of end users (versus accounting or technological indicators of inputs into the system).

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 user 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 over the years for which we have consistent data, indicative of rapid growth in demand for network resources, congestion and well-know concerns about traffic shaping/throttling/network-neutrality. In other words, as demand for network resources due to the diffusion of 2nd generation application has grown, 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, platform and service based competition, NGN diffusion, and regulation. The appendix describes the variables and their sources. Table 4 present correlations among the variables that help explore if there is indeed any empirical association between investment inputs and the quality of Internet connectivity.

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

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 s a negative correlation between the level of per capita investments and all indicators of differences in network performance and its growth. Average and peak speeds of Internet connectivity also appear to have grown relatively slowly in countries with higher rates of investment and revenue growth subsequent to the financial crisis. This observation is relevant because it suggests some degree of catching up/convergence across the sample. 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 capital 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 digital infrastructure development. If efficiency gains from more competitive discipline 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.

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 with both peak and average broadband speeds. The positive link is particularly strong on peak measured speed, which can be viewed as an indicator of network capacity operators have installed to limit service quality degradation in high traffic periods (magnitude of coefficient on peak performance is around 7 to 10 time higher than on average speeds). Starting from the simplest possible 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 variations in: 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 the cost 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/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 to .2 Mbps in terms peak network quality/capacity.

Table 5. 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

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 digital infrastructure quality in the EU. This suggests other factors such a public policy, firm strategies, and catch-up processes may be driving the results. 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 simple empirical model in the last section helps explain the relative importance of different indicators of investment for explaining network infrastructure quality. However, they have limited explanatory power. This section presents the results of our search for factors that can help explain differences in measured broadband speeds 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 non-DSL/NGN diffusion. It would therefore be inappropriate to employ both indicators in a regression as it would lead to a double counting. Tables 5 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 given that various indicators emphasized by the literature seem to have little explanatory power. As noted, this is because the peak performance measures already control for variations in demand as they reflect network quality at the low-load state of the system. Nevertheless, we also present the results with respect to average network quality for comparison.

Table 6. Determinants of Digital 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

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 both average and peak speeds is the share of the market that non-incumbent entities have managed to acquire. In addition, peak network quality in 2012 was higher in countries that are ranked higher in the TRGI. Although the average price of unbundled loops and regulatory intensity are not significant in any of the

regressions, their relations with network quality has a negative sign, which stands in contrast to the broad TRGI measure of regulatory variation. Regulatory intensity appears to have little to do with network development, which is consistent with results by Bacache et al. (2013) detailed earlier.

Implications of the analysis with respect to long term network performance growth rates are more interesting. 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. This might seem counterintuitive, 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 long term digital infrastructure outcomes 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 to 7 times larger than the negative coefficients of per capita investment levels and entry. On average, a 1% increase in the ratio of investments to revenues generated around 3.5 Mbps to peak network capacity/quality. Since growth in demand for network resources consumes this capacity, the magnitude and statistical significance of this effect on average speed growth rates are smaller.

The determinants and impact of financial strategies by operators on digital 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. 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. The direction of causality between competitive discipline, financial strategies of firms, and network quality outcomes is therefore ambiguous.

5. Summary and Implications for Multilevel Governance in the EU

Under the regulated monopoly model for financing and governing organizations that operate copper telephone networks, policymakers were ultimately responsible for the outcomes and mistakes by managers of the firms that reduced access to and quality of the platform. 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 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 Internet

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 employed in the debates. The analysis illustrated that the direction of empirical association between regulation and investment depends very much on the construction of indicators for capturing these variables across jurisdictions. Furthermore, it indicated that results in previous studies may be driven at least in part by factors such as differences in external financial constraints and distinctive paths in the co-evolution of regulation, competition, and network development across Europe. 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. The lack of top-down monitoring in the implementation of EU rules in some incumbent member states made entry relatively more difficult, enabled owners of fixed assets in sunset platforms to deter entry, and limited incentives for the transition to next generation networks. Since the late 2000s this problem has become more apparent, explaining relatively high per capita expenditure levels and new policy initiatives in Western Europe.

Concerns about the quality of Internet connectivity and access to essential facilities in some member states provide the impetus for ongoing debates about the scope of European Commission's authority to regulate telecommunications (Ruhle & Reichl, 2009; Simpson, 2011; Montolio & Trillas, 2013). Countries that have already managed to develop local regulatory regimes that are effective in supporting digital infrastructure development would clearly have little incentive to relinquish their authority over access regulation to EU institutions and become exposed to the risks of policy errors/regulatory capture at the center. In places where local incumbents and local regulators have a close working relationship which appears to stifle competition, innovation, and technological change, giving up local regulatory authority may help promote the pace of progress toward next generation connectivity. As suggested by Laffont and Martimort (1998) at the onset of the process of deep integration in the EU, decentralization only works if it does not improve communication channels between local economic and political powers too much. Digital infrastructure policy in the EU and debates about the allocation of regulatory authority over essential facilities access/interconnection represent another manifestation of broader challenges associated with procedural regulatory autonomy in increasingly integrated markets. To the extent that separation of powers in multilevel systems of governance increases the transaction costs of capturing public policy, enhancing EU powers in this area may help promote the prospects for digital infrastructure development in some members. Nevertheless, the risks of policy failure/capture at the center are real, particularly for those who are doing relatively well on their own devices.

References

- Akamai Technologies (2012). State of the Internet reports. Retrieved from <http://www.akamai.com/stateoftheinternet/>
- Bacache, M., Bourreau, M., & Gaudin, G. (2013). Dynamic Entry and Investment in New Infrastructures: Empirical Evidence from the Fixed Broadband Industry. *Review of Industrial Organization*, 1-31.
- Bauer, J. (2010). Regulation, public policy, and investment in communications infrastructure. *Telecommunications Policy*, 34, 65-79.
- Bauer, J. and Shim, W. (2012) Effects of regulation on innovation in the information and communication sector. TPRC 2012.
- Bauer, S. Clark, D., & Lehr, W. (2010). Understanding broadband speed measurements, MITAS project white paper, Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology. Retrieved from <http://mitas.csail.mit.edu/>
- Bauer, S. Clark, D., & Lehr, W. (2012). A data driven exploration of broadband traffic issues: Growth, management, and policy. TPRC 2012. Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2029058
- Belloc, F., Nicita, A., & Rossi, M. (2012). Whither policy design for broadband penetration? Evidence from 30 OECD countries. *Telecommunications Policy*, 36, 5, 382-398.
- Berkman Center for Internet and Society (2010). Next generation connectivity. Cambridge, MA: Harvard University. Retrieved from <http://cyber.law.harvard.edu/pubrelease/broadband/>
- Bouckaert, J., van Dijk, T., & Verboven, F. (2010). Access regulation, competition, and broadband penetration: An international study. *Telecommunications Policy*, 34, 661-671.
- Briglauer, W., Ecker, G., & Gugler, K. (2013). The impact of Infrastructure and Service-based Competition on the Deployment of Next Generation Access Networks: Recent Evidence from the European Member States. *Information Economics and Policy*, 25, 3, 142-153.
- Bruno, C. (2012) Functional Separation and Economies of Vertical Integration in European Fixed Telecoms. Retrieved from http://www.hermesricerche.it/elements/WP_12_03_CB.pdf
- Cadman, R. (2007). Regulation and investment in European telecoms markets. European Competitive Telecommunications Association. Retrieved from http://spcnetwork.eu/uploads/European_investment_paper.pdf
- Cambini, C., & Jiang, Y. (2009). Broadband investment and regulation: A literature review. *Telecommunications Policy*, 33, 559-574.
- Cambini, C. & Silvestri, V. (2012). Technology investment and alternative regulatory regimes with demand uncertainty. *Information Economics and Policy* 24 (3-4): 212-230.
- Christiansen, A., & Kerber, W. (2006). Competition policy with optimally differentiated rules instead of “per se rules vs rule of reason”. *Journal of Competition Law and Economics*, 2(2), 215-244.
- Choi, S. (2011). Facilities to service based competition, not service to facilities based, for broadband penetration: A comparative study between the United States and South Korea. *Telecommunications Policy*, 35(9), 804-817.

- De Bijl, P. W., & Peitz, M. (2005). Local loop unbundling in Europe: Experience, prospects and policy challenges: Unbundling facing new challenges. *Communications & Strategies*, (57), 33-57.
- European Commission (2013). Competition Decisions on State Aid to Broadband. Retrieved from http://ec.europa.eu/competition/sectors/telecommunications/broadband_decisions.pdf
- Ezell, S. Atkinson, R. Castro, D. & Ou G. (2009). The need for speed: The importance of next generation broadband networks. The Information Technology & Innovation Foundation (ITIF). Retrieved from <http://www.itif.org/files/2009-needforspeed.pdf>
- Grajek, M., & Roller, L. (2012). Regulation and investment in network industries: Evidence from European telecoms. *Journal of Law and Economics*, 55, 1, 189-216.
- Hoernig, S., Jay, S., Neu, W., Neumann, K. H., Plückebaum, T., & Vogelsang, I. (2012). Wholesale pricing, NGA take-up and competition. *Communications and Strategies*, (86), 153.
- Krämer, J., & Vogelsang, I. (2012). Co-investments and tacit collusion in regulated network industries: Experimental evidence. In *23rd European Regional ITS Conference, Vienna 2012* (No. 60389). International Telecommunications Society (ITS).
- Kroes, N. (2013). A Telecoms Single Market: Building a Connected Continent. http://europa.eu/rapid/press-release_SPEECH-13-622_en.htm.
- Laffont, J. J., & Martimort, D. (1998). Transaction costs, institutional design and the separation of powers. *European Economic Review*, 42(3), 673-684.
- Laffont, J.J. & Tirole, J. (2000). *Competition in telecommunications*. Cambridge MA. MIT Press.
- Lehr, W. & Kiessling, T. (1999). Telecommunications regulation in the United States and Europe: The case for centralized authority, In: *Competition, regulation and convergence: trends in telecommunications policy research*, Gillett, S.E. and Vogelsang, I., eds., Lawrence Elbaum Associates.
- Montolio, D., & Trillas, F. (2013). Regulatory federalism and industrial policy in broadband telecommunications. *Information Economics and Policy*.
- Polynomics (2012). Polynomics Regulation Index: <http://www.polynomics.ch/publikation-medien.php>
- Rajabiun, R. (2012). Private Enforcement and Judicial Discretion in the Evolution of Antitrust in the United States. *Journal of Competition Law and Economics*, 8(1), 187-230.
- Rajabiun, R. & Middleton, C. (2013a). Multilevel governance and digital infrastructure development: Evidence from Canada. *Telecommunications Policy*, 37, 9, 702-714.
- Rajabiun, R. & Middleton, C. (2013b). Lemons on the Edge of the Internet: Technological Convergence and Misleading Advertising in the Provision of Internet Access Services. TPRC 2013. Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2241563
- Ruhle, E. O., & Reichl, W. (2009). Incentives for investments in next generation access and customer choice: a dichotomy?. *Intereconomics*, 44(1), 30-40.

- Simpson, S. (2011). 'New' governance in European Union policy making: Policy innovation or political compromise in European telecommunications? *West European Politics*, 34, 5, 1114-1133.
- Sun, J-M & Pelkmans, J. (1995). Why liberalisation needs centralisation: Subsidiarity and EU Telecoms, *World Economy*, 18, 5, 635-64.
- Ware, H., & Dippon, C. M. (2010). Wholesale unbundling and intermodal competition. *Telecommunications Policy*, 34(1), 54-64.
- Waverman, L., & Koutroumpis, P. (2011). Benchmarking telecoms regulation—the telecommunications regulatory governance index (TRGI). *Telecommunications Policy*, 35(5), 450-468.
- Zenhäusern, P., Telser, H., Vaterlaus, S., & Mahler, P. (2007). Plaut Economics Regulation Index-Regulatory Density Index in Telecommunications With Particular Consideration of Investment Incentives. *Polynomics AG, Olten, Switzerland*.

Appendix: 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 2007-2012	Akamai Technologies
PeakG	%	Average annual growth in peak/maximum connection speeds between 2007-2012	Akamai Technologies
InvL	euro	Average annual per capita fixed capital expenditures in telecom network infrastructure between 2009-2011	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 & Koutroumpis (2011)
Regtrans	(0-100)	Index of telecom regulatory transparency	Waverman & Koutroumpis (2011)
RegInd	(0-100)	Index of telecom regulatory independence	Waverman & Koutroumpis (2011)
RegRes	(0-100)	Index of resource available for telecom regulation	Waverman & Koutroumpis (2011)
Enforc	(0-100)	Index of enforcement of telecom regulations	Waverman & Koutroumpis (2011)
TRGI	(0-100)	Telecom Regulatory Governance Index	Waverman & Koutroumpis (2011)