

Briglauer, Wolfgang; Stocker, Volker; Whalley, Jason

Conference Paper

Public Policy Targets in EU Broadband Markets: The Role of Technological Neutrality

29th European Regional Conference of the International Telecommunications Society (ITS): "Towards a Digital Future: Turning Technology into Markets?", Trento, Italy, 1st - 4th August, 2018

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Briglauer, Wolfgang; Stocker, Volker; Whalley, Jason (2018) : Public Policy Targets in EU Broadband Markets: The Role of Technological Neutrality, 29th European Regional Conference of the International Telecommunications Society (ITS): "Towards a Digital Future: Turning Technology into Markets?", Trento, Italy, 1st - 4th August, 2018, International Telecommunications Society (ITS), Calgary

This Version is available at:

<https://hdl.handle.net/10419/184936>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

Public Policy Targets in EU Broadband Markets: The Role of Technological Neutrality

Wolfgang Briglauer^{1*}, Volker Stocker², Jason Whalley³

1 - Vienna University of Economics and Business, Research Institute for Regulatory Economics, Vienna; ZEW Centre for European Economic Research, Mannheim, Germany.

2 - Chair of Network Economics, Competition Economics and Transport Science, Institute of Economics, University of Freiburg, Freiburg, Germany.

3 - Newcastle Business School, Northumbria University, Newcastle, UK; Institute of Mines-Télécom Business School, Evry, France.

**Corresponding author*

E: briglauer@zew.de.

Abstract

The European Commission has recently sought to substantially revise how it regulates the telecommunication industry, with a key goal being to incentivise investment in high-speed broadband networks. Ambitious goals have been set regarding the availability and quality of broadband across the European Union, initially in the ‘Digital Agenda for Europe’ and more recently in its ‘Gigabit strategy’. These goals reflect the view of many that there are widespread and significant socio-economic benefits associated with broadband.

Our analysis explores the consequence of target setting at a European level, in terms of encouraging investment and picking which technology should be adopted within the context of technological neutrality. We demonstrate that while public policy targets favour specific technologies, especially when the target is defined with regards to fast broadband speeds, the technological choices that occur within a Member State are shaped by the complex and dynamic interaction between a series of path dependencies that may vary significantly across as well as within Member States. Furthermore, taking into account the ecosystem’s tremendous evolution, the technological choices that are made within markets reflect both demand and supply uncertainties.

To assist with understanding the interaction between those forces that shape, to lesser or greater extent, the choice of one technology over another, we propose a four-phase framework. This framework is not a definitive statement of the relationships that we have identified, but rather serves as a mechanism that illustrates the challenges associated with adopting and then sticking with technological neutrality in policy making.

Keywords: Broadband, technological neutrality, fibre networks, 5G, path dependency, EU public policies

JEL classification: L38, L50, L52, L96

1 Introduction

On September 14, 2016, the European Commission (EC) published its proposal for establishing the European Electronic Communications Code, which would substantially revise the existing regulatory framework (European Commission, 2016a, hereinafter referred to as ‘CODE’). While agreement on the proposal was reached in June (European Commission, 2018), one of the CODE’s main goals is to incentivize investment in new high-speed broadband infrastructure. Given the high levels of investment that a comprehensive high-speed broadband deployment requires, investment incentives are essential. Furthermore, if we consider all the market developments to date related to declining communications revenues and actual coverage and adoption patterns in most European Union (EU) Member States (European Commission, 2017), it cannot be assumed that the existing market conditions will result in wide-ranging coverage – including rural and remote areas – with high-speed broadband infrastructures and high take-up of respective broadband services in the foreseeable future.

In view of the potential welfare gains,¹ and in order to push high-speed broadband deployment, the EC had already set several broadband targets in 2010. The Digital Agenda for Europe (DAE) “*seeks to ensure that, by 2020, (i) all Europeans will have access to internet speeds of above 30 Mbit/s and (ii) 50% or more of European households will subscribe to internet connections above 100 Mbit/s*” (European Commission, 2010, p. 19). Building on these objectives, in 2016 the EC expressed its more ambitious longer-term objectives for 2025 emphasizing the promotion of “*very-high capacity*” fibre-based networks, which enable gigabit-connectivity via wireline and/or wireless communications infrastructures. In particular, the European Commission (2016b, pp. 35-36) proposed three strategic objectives in its ‘Gigabit strategy’:

1. Gigabit connectivity for the main socio-economic drivers;
2. 5G mobile data connectivity for all urban areas and transport paths; and,

¹ These are related to positive externalities as a broad-scale broadband infrastructure exhibits a general purpose technology character (Bresnahan and Trajtenberg, 1995). Broadband access provides the necessary input for an innovative and versatile ICT ecosystem and can thus be considered a formative force in facilitating innovational complementarities that encourage positive spillovers across major economic sectors (Bauer and Knieps, 2018; OECD, 2008, pp. 8-13; Schultze and Whitt, 2016, p. 86).

3. access to Internet connections offering at least 100 Mbit/s for all European households.

Assuming that high-speed broadband deployment does indeed go hand-in-hand with substantial welfare gains, the question first arises as to which policy schemes enhance or diminish investment incentives? Whereas sector-specific access regulations appear to be a relevant policy instrument to tackle network-specific (significant) market power, in those areas in which the roll-out of desired network infrastructures would not be viable, incentivizing network roll-out through sector-specific access regulations is not an option.² In these circumstances, public policies based on subsidies would be a considerably more effective instrument to ensure the supply of broadband access in non-profitable ‘white areas’, especially when achieving ubiquitous deployment targets as outlined by the European Commission (2010, 2016b).

In achieving these targets, our key research question emerges: to examine whether and to what extent public policies – based on sector-specific regulations or subsidies – should favour specific technological choices in order to incentivize investments, or whether policy makers should instead delegate the decision on the optimal technology mix to market forces? This is an important question as, depending on the exact specification of broadband targets, several deployment scenarios based on different technical options appear to be technically feasible. In this context, proponents of the so-called ‘technological neutrality’ principle argue that none of the feasible network scenarios should be favoured a priori. Instead of such top-down elements that critically determine and pick winners, they tend to argue that market forces should identify winning technologies based on entrepreneurial search processes.³

The European Commission (2009, recital 18) explicitly introduced the concept of technological neutrality into its regulatory framework, defining it as follows:

“The requirement for Member States to ensure that national regulatory authorities take the utmost account of the desirability of making regulation technologically neutral, that is to say that it neither imposes nor discriminates in favour of the use of a particular type of technology, does not

² See Briglauer and Cambini (2017) who discuss the impact of various regulatory regimes on incentivizing investment in new broadband infrastructure. Our analysis in parts, in particular in Sections 2 and 3, builds on Briglauer and Cambini (2017), which was initially prepared for Deutsche Telekom, and should be viewed as an independent piece of research.

³ See Cave and Shortall (2016), for alternative interpretations of the technological neutrality principle.

preclude the taking of proportionate steps to promote certain specific services where this is justified, for example, digital television as a means for increasing spectrum efficiency.”

While this implies the general desirability of technological neutrality, promoting a set of or even a single specific technology might sometimes be justified. In this paper, our aim is to examine the desirability of technological neutrality in conjunction with public targets as guiding policy principles in the case of high-speed broadband deployment in the specific context of the recent major review of the EU regulatory framework for electronic communications. In doing so, past market developments in EU Member States are taken into account.

The rest of this article is structured as follows: While Section 2 provides an overview of the relevant broadband access technologies as well as corresponding terminology and definitions, market developments related to all relevant types of broadband infrastructure and the adoption of broadband services are presented in Section 3. Against this background and based on an analysis of the role of path dependencies for network evolution, Section 4 then evaluates the role and relevance of technological neutrality and public policy targets as guiding principles in high-speed EU broadband markets and provides a conceptual framework for policy decision making. The final Section 5 summarizes and provides policy recommendations.

2 The broadband ecosystem: technologies, fiberisation and convergence

Historically, fixed-line legacy telecommunications networks were based on twisted-pair copper infrastructures that were dedicated to and purpose-built for the delivery of voice telephony services. It was these legacy networks that initially provided the infrastructural basis for the early use of the commercial Internet via narrowband dial-up modems (Clark et al., 2006; Valdar, 2006, pp. 29-31). Due to the growing popularity of the Internet, and the tremendous array of associated innovations that soon began to become available, it was not long before narrowband access networks were upgraded to xDSL technologies⁴ capable of delivering ‘first-generation’ broadband services.

This marked the beginning of rapidly increasing Internet access capabilities based on the growing ‘fiberisation’ of broadband networks that saw twisted-pair copper-based network

⁴ xDSL is a generic term used for the ‘Digital Subscriber Line’ technologies, which provide Internet access by transmitting digital data over copper-wire lines. “Very-high-bit-rate digital subscriber line” (VDSL), VDSL2 and VDSL vectoring are currently the most advanced DSL-based technologies.

elements being (gradually) replaced by fibre optic elements. The investments were significantly spurred on by the widening and rapidly evolving variety of content and application services accessible via the Internet. In this process, the migration from narrowband to broadband implied a paradigm shift. The formerly purpose-built telephone infrastructure has evolved into a multi- or general-purpose broadband platform that supports a wide variety of content and application services, and thus provides the infrastructural basis for far-reaching innovative activity. Innovational complementarities may further create incentives for network investments.⁵ Even though corresponding broadband access technologies can support the simultaneous use of voice, video and data services on an IP-basis, their performance and capabilities are greatly limited by the length of the copper-based part of the local access loop. The closer fibre-optic cables are deployed to the customer's premise, that is, the 'deeper' fibre is deployed within the access network, the higher the data rates that can be achieved (Zhao et al., 2014, p. 10; FTTH Council Europe, 2018, pp. 12-13).

Depending on the reach of fibre, different 'next generation access' (NGA) broadband access technologies are available which are all based, at least partly, on fibre-optical transmission in the access network. In contrast to traditional DSL technologies that rely on a twisted-pair copper line from the local exchange (Fibre to the Exchange, FTTE_x) to the customer premises (Zarnekow et al., 2013, p. 120), FTTC is referred to when advanced DSL-based access technologies such as VDSL2 are delivered by hybrid copper-fibre local access loops. While fibre extends to street cabinets, copper lines typically cover the last (several hundred) meters and connect street cabinets to the customer premises. Fibre to the distribution point (FTTD_p) supported by VDSL/G.fast is another recent hybrid copper-fibre broadband access technology. From an architectural point of view, FTTD_p is similar to FTTC but fibre is deployed deeper into the access network so that the distance data packets need to travel via twisted-pair copper lines is typically reduced to less than 250 meters (FTTH Council Europe, 2018, p. 12). Taking into account the set of available hybrid-broadband access technologies and complementary techniques (e.g., vectoring or G.fast), it is currently possible to provide data rates of up to several hundred Mbit/s. Furthermore, technological innovations - XG.fast - are

⁵ See, among others, Bauer and Knieps (2018) for a recent and detailed discussion of innovational complementarities in the current Internet ecosystem.

expected to bring further significant performance improvements and yield data rates of multiple Gbit/s (Timmers et al., 2018, p. 5).

The next stage of fiberisation is achieved when fibre is deployed even deeper into the local access network and eventually replaces all copper-based elements. Fibre to the building (FTTB) technologies require the fibre-optic cables to be located close to or inside a building. While it needs to be noted that several configurations exist in which metallic in-house cables are partly replaced by fibre, when technical and economic considerations render it feasible to completely eliminate copper lines, even in-house, full-fiberisation is achieved. In these cases, each subscriber can be connected by a (dedicated) fibre access line, a system referred to as fibre to the home (FTTH). FTTH is said to be ‘future proof’ as available data rates are limited by components within the delivery chain other than the fibre infrastructure (e.g., the terminal equipment or network nodes like servers or routers). Even though FTTH technologies may vary in terms of their architecture, the data rates that can be obtained from FTTH are almost unlimited (Briglauer and Cambini, 2017, pp. 3-5; FTTH Council Europe, 2018, pp. 11-12; Coomans et al., 2015; Timmers et al., 2018). Figure 1 (below) provides an overview of the relevant FTTx-based access technologies.

In addition to the FTTx architectures presented above, NGA networks might also be realized based on broadband access technologies that rely on the coaxial-cable infrastructure that was originally built and used for the unidirectional delivery of cable television (CATV). Upgrading strategies enable hybrid fibre-coax (HFC) broadband Internet access. Fiberisation takes place as fibre is deployed deeper into the access network and thus closer to the last amplifier. Through the use of DOCSIS 3.0 technology, data rates of up to 400 Mbit/s can be provided (Zhao et al. 2014, p. 15). While data transmission via coaxial cables renders available data rates less sensitive to distance than in the case of FTTx technologies that rely on the use of twisted-pair copper cables, the underlying architectural design and resulting network topology leads to a capacity sharing situation that is fundamentally different from the FTTx technologies as described above. From the fibre node, a single coaxial cable typically connects to multiple customers (tree structure). Thus (downstream) transmission capacity is shared between all active users that are connected via the same network tree. During peak times this may cause significant performance reductions such as, for example, reduced available data rates. In addition, HFC networks are optimized asymmetrically for downstream usage. Thus, upstream

capacity is typically more limited than it is for FTTx technologies (Tanenbaum and Wetherall, 2011, pp. 180-183; Zhao et al., 2014, p. 15). The recent DOCSIS 3.1 version, which is soon expected to be deployed on a larger scale, can provide data rates of up to 10 Gbit/s.⁶

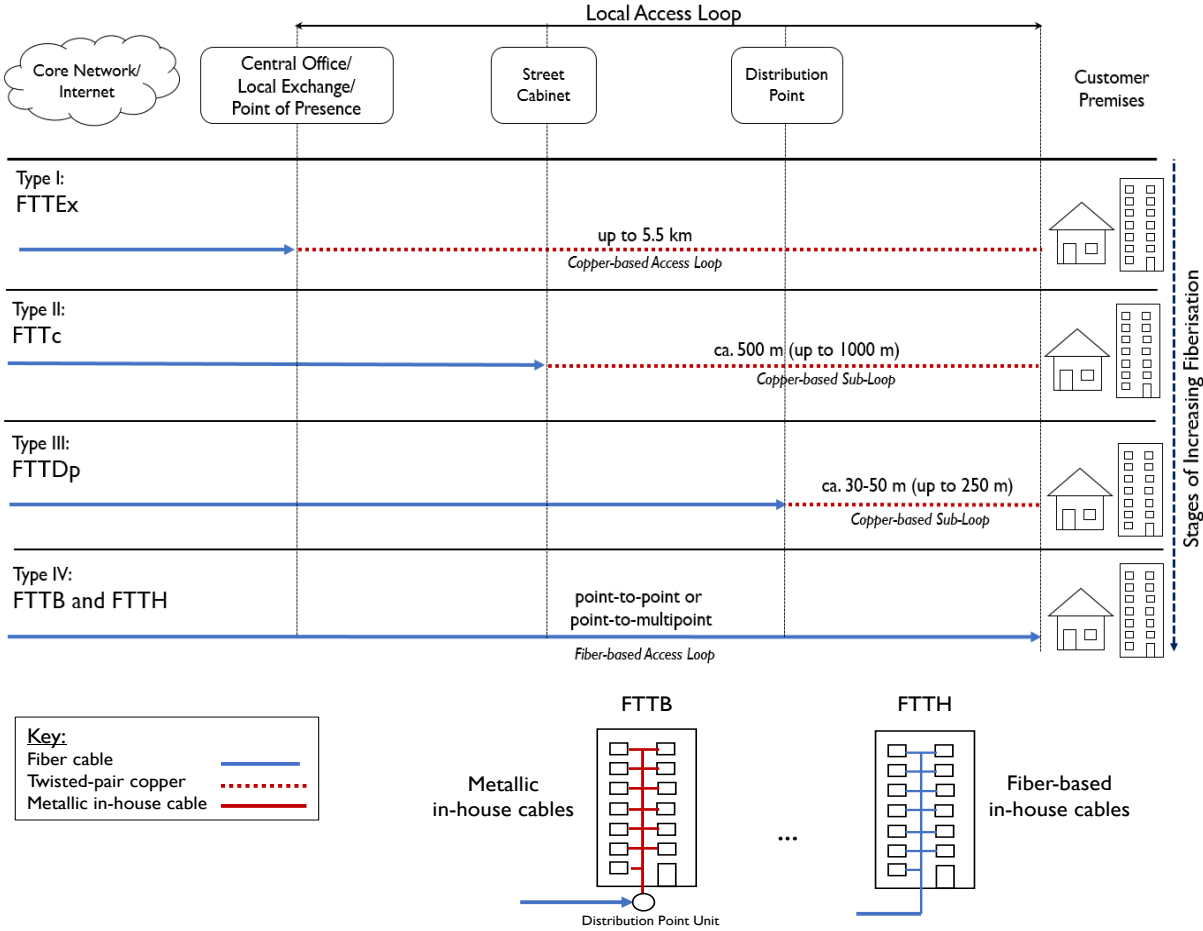


Figure 1: Relevant FTTx-based network architectures

Source: FTTH Council Europe, 2018, pp. 12-14; Timmers et al., 2018, pp. 4-5; Zhao et al., 2014, pp. 6-7.

Mobile broadband services have become widely available. While the roll-out of 3G-based mobile access technologies started more than a decade ago, the more recent standards for 4G-based broadband access enhance spectral efficiency and facilitate maximum data rates that are almost comparable to those provided via fixed-line hybrid-fibre NGA systems (Wannstrom,

⁶ Recently in Korea SKBroadband rolled out HFC on the basis of DOCSIS 3.1 and achieved data rates of 4 Gbit/s upstream and 1 Gbit/s downstream. Deployments providing 10 Gbit/s downstream and 5 Gbit/s upstream data rates are envisaged (Cisco, 2018).

2013). Even though corresponding technologies have been deployed in many Member States, the quality of data transmission as illustrated by, for example, available data rates, depends on a host of factors. In its most recent market recommendation, the European Commission (2014) considers 4G to be a viable option to wireline NGA broadband services in the medium term but currently is not yet a close enough substitute for most consumer segments.

This, however, may change with further advances in mobile technologies. 5G, in particular, is expected to yield significant increases in available data rates, and is capable of providing ultra-reliable data transmission at ultra-low latencies. This can be achieved due to a number of innovations. For example, the available frequency spectrum is widened through the use of high frequency millimetre wave bands (Ofcom, 2018, pp. 17-23; European Commission, 2016c, pp. 5-6) and both efficiency and flexibility are increased compared to previous generations of mobile access technologies (Ofcom, 2018, pp. 15-16; DotEcon and Axon, 2018, pp. 21-23). In addition, especially in high demand areas characterized by large numbers of users, devices or sensors, and/or where high frequencies are used to deliver ultra-low latency services, small cells (or: ‘microcells’) that are ‘fibre-fed’ are likely to be deployed (Ofcom, 2018, pp. 15-16 and 23-24; DotEcon and Axon, 2018, pp. 20-24; Adtran, 2018, pp. 4-5). 5G is expected to facilitate the provision of a variety of innovative services in many sectors such as ‘Autonomous driving’, ‘Machine-to-machine communications’, ‘Internet of things’ (IoT), ‘Smart Energy’, ‘Smart farming’, etc.⁷ Within the context of the IoT or the tactile Internet, 5G can facilitate communications between large amounts of connected devices and sensors that often have stringent requirements for the performance and reliability of data transmission (Ofcom, 2018, pp. 14-15). In addition, 5G may present a cost-efficient substitute for fixed wireless broadband access in rural areas (Littmann et al., 2017, pp. 9 and 19; DotEcon and Axon, 2018, pp. 23-24). As 5G is, at its core, a fibre-based technology that enables ubiquitous mobility as well as high performance and ultra-reliable data transmission, complementarities in the roll-out and use of fibre between fixed and mobile access technologies will become increasingly important and lead to a densification of fibre-based network infrastructures (European Commission, 2016c, pp. 6-7; Adtran, 2018, pp. 4-5; Ofcom, 2018, pp. 26-27; DotEcon and Axon, 2018, pp. 93, 96; Accenture, 2017). In terms of optimal FTTx migration

⁷ For a comprehensive overview of potential use cases, see DotEcon and Axon (2018, pp. 28-57).

scenarios and fixed-mobile integration in access networks, however, these upcoming developments in the mobile sector also give rise to considerable technological uncertainties.⁸

In summary: from the above it can be readily seen that technological innovations in hybrid ‘second-life copper/coax’ technologies that do not rely on the complete replacement of metallic components in the local access network via fibre can effectively contribute to delivering public broadband targets. Significantly, these technologies can contribute towards achieving the bandwidth objectives laid out in the DAE but also the more ambitious targets formulated as part of the 2025 Gigabit strategy. In other words, although full-fibre FTTH deployments constitute the ultimate technological infrastructural solution capable of delivering virtually unlimited data rates, a range of hybrid NGA technologies are capable of delivering the public policy targets and can thus contribute to an efficient migration path towards FTTH and 5G networks. Natural complementarities with 5G mobile technology arise as these technologies can only achieve their potential if they have adequate connectivity to the ‘fibre backhaul’ which further necessitates substantial investment activities in order to directly connect small cells to fibre-based networks. Eventually, FTTH networks using XG.fast transmission technology could become a cost-efficient fibre backhaul for 5G networks (Coomans et al., 2015, p. 83).

3 Relevant market developments

Figure 2 shows the adoption of broadband services based on all available wireline broadband technologies. According to this data, most broadband services are still based on various DSL-based access technologies (including FTTC/VDSL), followed by broadband services from CATV network providers (including different DOCSIS versions). In contrast, there are only a small number of countries in which optical fibre-based FTTH/B Internet connections make up a substantial proportion of the total connections. A comparison of Member States shows that the figures for a number of countries vary, sometimes considerably, from this average. In Belgium, for example, more than 50% of subscribed connections use the infrastructure from CATV-based networks, whereas in other countries, such as Greece or Italy, DSL or VDSL is used almost exclusively. As the latter two countries never had a CATV network, this is a natural

⁸ For a discussion of the symbiotic relationship between 5G and FTTH deployments see Adtran (2018) or Littmann et al. (2017).

result due to strong path dependencies related to the existence and structure of first generation (or: ‘legacy’) networks. More generally, it appears that historic decisions on the deployment of legacy networks play an important role in understanding the status quo and the heterogeneous network evolution paths between as well as within individual countries.

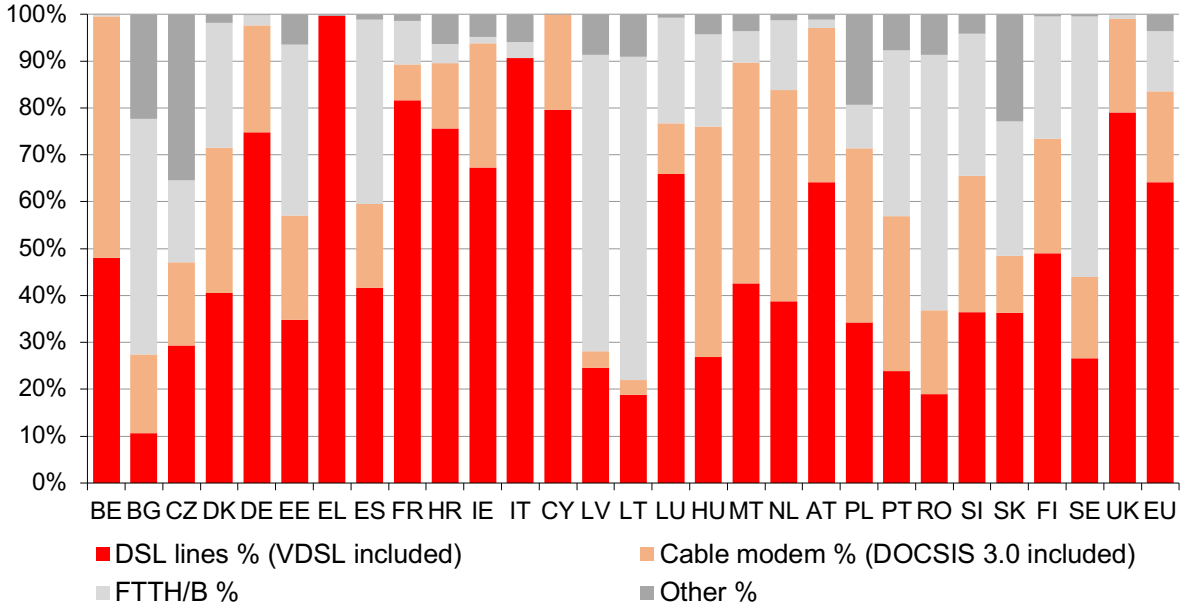


Figure 2: Technology market shares in fixed broadband subscriptions (July 2016)

Source: European Commission (2017)

Figure 3 shows the availability of FTTH/B broadband infrastructure coverage. It appears that those countries that lead the way in terms of the adoption of FTTH/B connections (Figure 2) are also among those with high FTTH/B availability. As Figure 2 and Figure 3 show in more detail, it is primarily in northern and eastern European countries that FTTH/B connections account for a larger share of all wireline broadband connections. In particular, these two regional groups are comprised of 12 out of the 16 countries with above EU average levels in Figure 3. One basic difference can be attributed to previously implemented public broadband incentive programs and the far-reaching role of the municipality sector in northern European countries (Briglauer and Gugler, 2013; Godlovitch et al., 2015). In terms of new FTTH/B broadband infrastructures, local authorities and utility companies are strongly engaged in FTTH/B deployment activities in northern European countries (Crandall et al., 2013, p. 274; Finnie, 2012, p. 8).

The comparatively good quality of the legacy copper-based telecommunications networks and CATV networks in western European countries represent high opportunity costs, particularly for investment in FTTH/B-based connections. Consequently, in some of the largest western, central and southern European countries existing FTTH/B deployment projects typically focus on only a small number of urban regions. FTTH/B investment in those countries would ‘cannibalize’ economic benefits from the first-generation broadband related services, which represents corresponding opportunity costs associated with investment in access infrastructures that would have to be newly built. This ‘replacement effect’ has been further strengthened over recent years through massive technological advances in second-life copper/coax technologies that subsequently enhance their capabilities. ‘Reusing’ legacy infrastructures has proven to be of high economic value (Coomans et al., 2015). In contrast, eastern European countries typically exhibit low quality legacy networks and thus experience a low replacement effect which opens up the opportunity of technological leapfrogging and to directly migrate to FTTH/B-based network deployments.

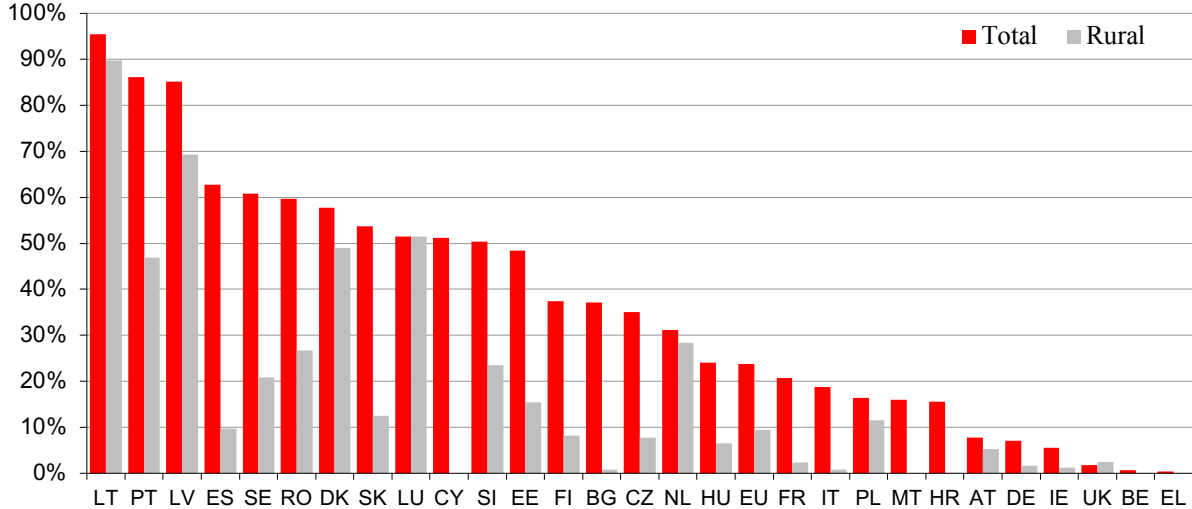


Figure 3: FTTH/B coverage (June 2016)

Source: European Commission (2017)

It is important to note here that high average coverage levels in total numbers do not imply that all households have coverage (as sought by the DAE’s and the Gigabit strategy’s coverage targets). Instead Figure 3 and Figure 4 show that there is substantial geographical

intra-country variation between rural and urban areas as regards FTTH/B and NGA coverage and inter-state coverage variation between EU Member States. The underlying heterogeneity due to differences in deployment costs and/or consumer demand patterns has strong implications on the economics of roll-out and, as a consequence, on network evolution. Substantial heterogeneity also suggests that homogenous policy targets might have adverse welfare effects in certain areas. Technology neutrality shall minimize the deviations from market-driven technology choices and associated distortions.

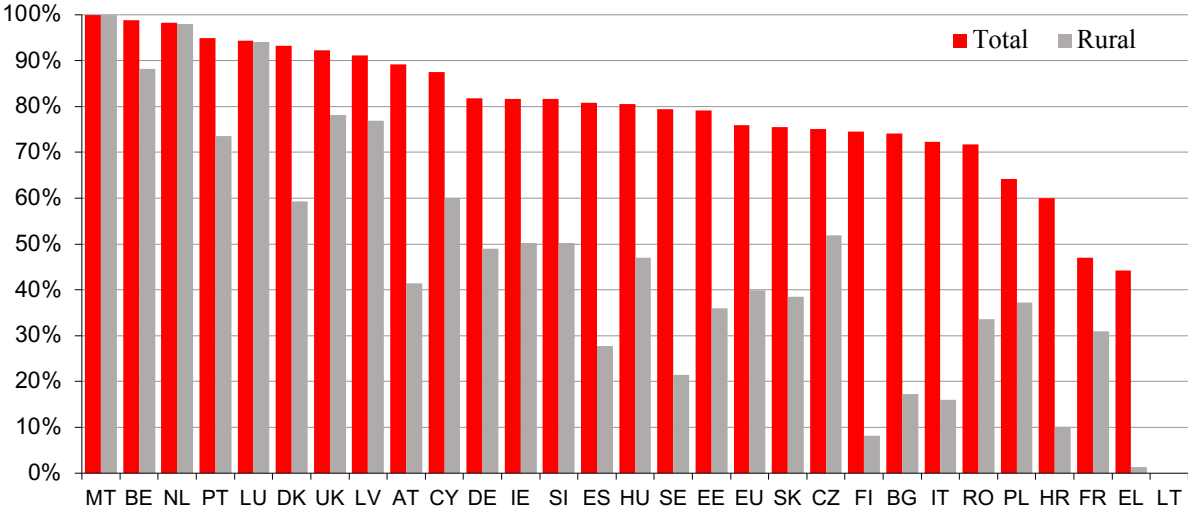


Figure 4: NGA coverage in rural areas and in total (June 2016)

Source: European Commission (2017); Data for LT not available

Figure 5 displays take-up rates, which are defined as the number of subscribed connections in relation to the number of connections available as a percentage. After years of moderate growth since 2011, in 2016 the take-up rate is still at a rather low level of 36%. This suggests that there is substantial inertia for consumers, who appear to be largely content with basic broadband services. Conventional broadband packages enjoy broad acceptance among many consumers in most EU Member States, which leads to significant inertia on the part of the consumer and thus hinders migration to new technologies. This, in turn, leads to low NGA take-up rates. The exception to this rule is when the benefits of migration are significant enough and transparent enough for consumers (Grajek and Kretschmer, 2009; Briglauer, 2014). However, most of the empirical evidence to date suggests that “customers are likely to have a high incremental willingness to pay for a high speed service, but a low incremental willingness

to pay for very high speed services” (Parcu, 2016, p. 52). For broadband providers, low take-up rates give rise to substantial demand uncertainties which diminish expected profits and hence ex ante investment incentives.

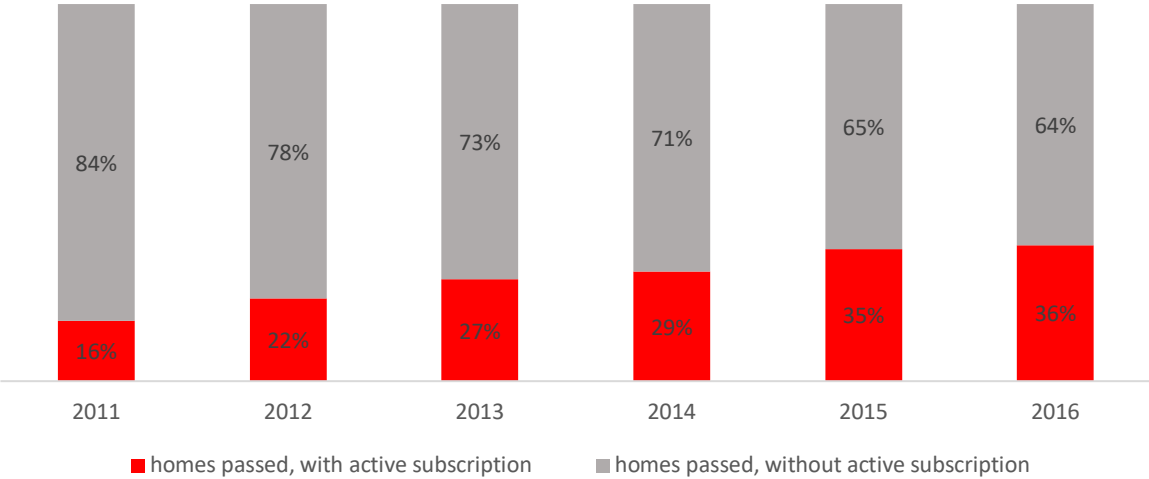


Figure 5: NGA take-up of broadband subscriptions as a % of all homes passed (EU level)

Source: European Commission (2017)

In summary: it first appears that coverage and adoption of NGA broadband varies widely with respect to access technologies and geography (urban vs. rural) between as well as within Member States. Heterogeneity represents a clear limitation to the goal of harmonizing broadband deployment policies and targets, especially in those cases in which heterogeneity is the result of differing demand and cost conditions. Secondly, persistently low take-up rates indicate that low adoption on the demand side actually represents a major issue that also gives rise to costly over-capacities on the supply side. Thirdly, NGA investment incentives will be further diminished in case of technological uncertainties related to 5G network roll-out and future integration of fixed and mobile access networks. Investment in FTTH/B networks are also challenged by future technological progress of second-life copper-/coax technologies. Fourthly, rural or white areas represent a remaining challenge in view of ubiquitous coverage goals in most Member States. Accordingly, public policy measures in white areas will be needed if rapid and broad-scale NGA deployment is considered desirable. Here politicians are confronted with trade-offs in view of faster deployment primarily based on hybrid-NGA

networks vis-à-vis the costlier and more time-consuming roll-out of FTTH/B networks capable of delivering virtually unlimited bandwidth levels.

4 A critical assessment of technological neutrality and public targets as policy principles in the EU regulatory framework

Public targets are economically justified if they compensate for situations in which markets do not supply politically desired broadband coverage or quality. In case of substantial positive externalities related to the deployment and adoption of certain NGA network scenarios, technological neutrality might in fact lead to market failure (Cave and Shortall, 2016, p. 31). This might happen, for example, if welfare is lost due to a too slow migration towards FTTH/B networks exhibiting high externalities as an outcome of strong legacy-based path dependencies.

Below we first describe and analyse the role of the different types of path dependencies that interactively shape network evolution (Section 4.1) before we assess the role of technological neutrality against the background of recent market developments and the current EU regulatory framework (Section 4.2). Based on this discussion we provide a critical appraisal on the economic relevance of public policy targets and their impact on technological neutrality (Section 4.3). Finally, in Section 4.4 we provide based on our findings a summarizing conceptual framework for technological neutrality policy decision making.

4.1 Path dependencies, broadband network evolution and complementary innovations

Understanding the cost-benefit trade-offs, the economics of the roll-out of different broadband access technologies and private and public investment decisions, requires including in the analysis those forces that drive the evolution of the Internet ecosystem. For the analysis of the availability and evolution of broadband access infrastructures, a particularly useful starting point is to note that the relevant trade-offs are shaped by a range of factors with the most important arguably being: the history and current state of network infrastructure, geographical characteristics as well as competition and regulation within relevant markets.

Not only do those market conditions related to geography (e.g., specific topographical characteristics), historical decisions (e.g., legacy network deployments and regulations) and specific strategies at the firm level (e.g., network investments) shape the evolutionary trajectory of the Internet ecosystem, but they also significantly give rise to different dimensions of path

dependencies.⁹ When discussing broadband targets and framing corresponding investment problems the analysis of path dependencies helps to explain market-driven investment incentives. This, in turn, yields insights for the design of appropriate public policies.

While Knieps and Zenhäusern (2015), among others, emphasize the role of path dependencies in the context of broadband network evolution, a recent report by the Florence School of Regulation (2017, pp. 26-31) identifies and describes four categories of relevant path dependencies. Drawing on this report, we describe the many dimensions of path dependencies and their dynamic interdependencies and show their importance for the design and assessment of public policies for broadband.

We start with a set of ‘invariable’ and thus exogenous factors related to geographical, especially topographical characteristics. These factors also constitute a formative force in the evolution of the Internet ecosystem as they strongly impact on demand and cost conditions, and critically impact on the economics of broadband roll-out and private investment incentives. Historically, these factors have shaped the evolution of network infrastructures, initially favouring urban, commercial and high population density areas over other areas. Furthermore, it can be derived that they favour ‘status quo’ orientated investments that see network operators largely invest in their existing infrastructure, favour upgrades of existing technologies and only reluctantly expand coverage in terms of ‘disruptive’ investment in FTTH/B networks. Not only are geographical (topographical) characteristics reflected in a series of inter-relationships between legacy decisions, the regulatory context and the nature of competitive pressures in the market, they also impact on a set of additional dimensions of path dependencies which should – due to their profound impact on network evolution – be considered when designing broadband policies.

A first dimension of the relevant path dependencies arising from the current state of infrastructure deployments are subsumed under the term ‘legacy path dependencies’. Shaped by geographical (topographical) characteristics, significant variations in the deployment of network infrastructures can be observed across several dimensions such as the urban landscape or the location of commercial, industrial and transportation hubs. Significantly, the existence, coverage and quality of legacy telecommunications and CATV networks as well as utility

⁹ In generic terms, path dependencies describe dynamic “*processes involving historically contingent evolution*” (David, 2007, p. 92) and constitute a well-established concept in economics and social sciences (David, 1985; 2007; Arthur, 1989).

infrastructures, rights of way and ducts,¹⁰ have a strong influence on status quo broadband deployments – especially in terms of their availability, topology and configuration – and also significantly impact optimal migration paths to FTTH/B.

On the one hand, these path dependencies shape the technological upgradability as well as the economic scalability of existing broadband deployments and also yield implications for the economics of delivering high-speed broadband to those areas where only passive or no infrastructure elements are available. As Section 3 has shown, corresponding path dependencies may vary strongly between and within EU Member States and thus have significant implications for the design of policies aimed at delivering ubiquitous high-speed broadband. Given the potentials of second-life broadband access technologies that can make efficient use of high quality elements of legacy infrastructures, these may present options for cost effective migration to meet broadband targets. Thus, in those areas where high quality legacy networks are available, high opportunity costs to migrate to FTTH/B imply strong legacy path dependencies. At the other extreme, legacy path dependencies are less relevant in those areas where no first-life broadband access infrastructures are available.

Intimately linked to legacy path dependencies are ‘regulatory and competitive path dependencies’. Regulatory approaches and public policies, as well as the extent of regulatory certainty, shape the competitive environment and influence the market-driven investment incentives in network infrastructures. For example, public policies and universal service regulations – which are often associated with pre-liberalised and pre-harmonized national markets – have in many countries created ubiquitous access to utility infrastructures as well as to the public telephone network. Market structures may further be shaped by the type(s) and intensity of facilities-based and service-based competition. While the possibilities for facilities-based (inter-platform) competition is based on the existence of a rival broadband access network architecture (which typically means the CATV network), the possibilities for and intensity of service-based (intra-platform) competition fundamentally rests on sector-specific access regulations.¹¹ In addition, network neutrality regulations may not only affect competition

¹⁰ Rights of way and passive infrastructure elements like ducts and ductworks of utility networks can be used for the roll-out of broadband on the basis of infrastructure sharing approaches (e.g., FTTH Council, 2018).

¹¹ For a qualitative discussion of regulatory path dependencies underlying broadband markets the reader is referred to Cave and Feasey (2017) and Knieps and Zenhäusern (2015), and to Briglauer et al. (2017) for a recent empirical investigation relating inter alia NGA broadband regulations to first-generation broadband

at the service level but also constrain the entrepreneurial flexibility of broadband access service providers to charge for the delivery of Internet content and applications. Considering regulatory-induced changes in revenue sharing between broadband providers and providers of content and applications, this may further affect investment decisions.

While the inter-relationships between the two aforementioned types of path dependencies have already been described, these are linked to another type of path dependencies: strategic path dependencies. Strategic path dependencies are interrelated to legacy path dependencies as well as to regulatory and competitive path dependencies. Firstly, they reflect the technological limitations and the evolving cost-benefit trade-offs associated with the different options of broadband roll-out and significantly determine entrepreneurial investment incentives and thus market-driven migration paths. Secondly, they reflect and also inform regulations and public policies for broadband. While public policies may lead to a devaluation of existing assets, the political commitment to provide funds to deliver a pre-specified broadband target may strongly disincentivise (even otherwise profitable) private broadband. Not only may market-driven migration paths be distorted, but the delivery of the targets may be delayed due to strategic manoeuvring by broadband providers waiting to receive public funding. In extremis, private investments may even be crowded out by public funding (Valletti, 2016, p. 15).

Even though investments in broadband networks are significantly determined by the interacting set of path dependencies described above, it is necessary to adopt a broader picture to understand the investment decisions broadband providers are confronted with. Due to the modularity of the Internet (Yoo, 2016), complementary innovations have become integral components of the ecosystem.¹² Thus, even though these innovations do not require investment in broadband infrastructures, they significantly shape the nature of competition, the regulatory environment and the investment incentives of broadband providers. As such, the complementary innovations influence the path dependencies described above. Considering the evolution within the wider ecosystem requires recognition that the specific limitations and

regulations. Using EU level panel data the authors find evidence supporting both regulators pursuing normative objectives but also inefficiencies related to regulatory path dependence and bureaucracy goals of policy makers.

¹² The ecosystem is the outcome of a dynamic interplay between an evolving set of components at different layers that are owned, operated and controlled by a large amount of different and often competing entities (Stocker and Whalley, 2018).

broadband-related path dependencies may lead to rigidities or inertia in the basic network's capability to flexibly adapt to the rapidly changing set of demands. These have, in turn, created a series of (vertical) innovation spill-overs and subsequent innovations in technologically complementary network layers.

For example, innovative strategies for distributed content delivery on the basis of content delivery networks or data processing on the basis of distributed computing approaches (e.g., fog or edge computing) present 'topological innovations' that can help to localize traffic, intelligently balance network loads and mitigate the effects of suboptimal network infrastructure deployments (Stocker et al., 2017; Ai et al., 2018; Linthicum, n.d.). While Internet-based traffic flows thus become increasingly local, innovative end-point-based network management capabilities (e.g., adaptive streaming and responsive web design) and sophisticated compression techniques (e.g., video codecs) can help to reduce network utilization.¹³ Significantly, corresponding complementary innovations can increase consumer experience, postpone the need for network upgrades and thus broadband investments, and may further be used to circumvent regulatory constraints faced by companies.¹⁴

Advances in the online distribution of content on the basis of complementary innovations will encourage broadband adoption and increase bandwidth consumption. Similarly, and significantly, the development of new applications in the context of IoT such as those related to the smartification of infrastructures and connected (fully automated) cars as well as tactile Internet applications are expected to create unprecedented challenges for broadband infrastructures in terms of performance, reliability, mobility, and security (Accenture, 2017; Ofcom, 2018, p. 30; Knieps, 2017).

From these examples it becomes clear that complementary innovations change the nature of demand. But, as demand increases and is becoming more complex, the infrastructure related investment decision-making scope reflects past decisions (legacy path dependencies) as well as what can be charged for and needs to be recouped (regulatory and competitive path dependencies). These are simultaneously shaped by the strategy of the company (strategic path

¹³ For an overview of corresponding technologies and mechanisms see Begen and Timmerer (2017) and ZetaCast (2012).

¹⁴ For example, network neutrality regulations that constrain the contractual freedom of broadband access service providers to differentiate between different content and applications on the basis of innovative price and quality differentiation strategies may yield potentials for regulatory arbitrage and may also spur the cloudification and privatization of networks (Stocker et al., 2017; Huston, 2017, or Claffy et al., 2018).

dependencies) that may, for instance, prioritise the use of existing infrastructure over new investment or diversifying (i.e., vertically integrating) into content and applications to develop and exploit additional sources of revenues.¹⁵

If the network operator has a content orientated strategy, then conceivably the interaction between the three dimensions of path dependencies will be different. The diversification into content by a network operator could encourage them to further invest in fibre, bringing it closer to the end user so that the consumer experience is enhanced as bandwidth demands increase.¹⁶ The extent to which new fibre investment occurs is again influenced by competitive and regulatory factors (such as rights of ways or access to passive infrastructure elements) as these will shape the ability of the company to maintain or perhaps even raise prices or produce attractive content and so forth.

In summary: the inter-relationships that exist between the aforementioned path dependencies are depicted in Figure 7. Geographical (topographical) characteristics exert, to lesser or greater extents, an exogenous impact on the three identifiable dimensions of path dependencies that, in turn, dynamically interact with one another. Complementary innovations can be seen as being endogenously driven by these interdependencies which will themselves exert an impact on the set of interacting path dependencies.

¹⁵ See, for example, Whalley and Curwen (2017) for a discussion of how a legacy-based operator, British Telecom, diversified into the provision of content to encourage consumption of its broadband products.

¹⁶ Google, for example, launched a project to self-deploy FTTH infrastructure under the brand banner of 'Google Fiber' in 2010. While Google Fiber first made some substantial fiber roll-outs, it was confronted with low take-up rates and higher than expected deployment costs. As a consequence, Google fiber executives stopped wireline fiber deployment in 2016 (information available at: https://motherboard.vice.com/en_us/article/zmwkdx/eight-years-later-google-fiber-is-a-faint-echo-of-the-disruption-we-were-promised).

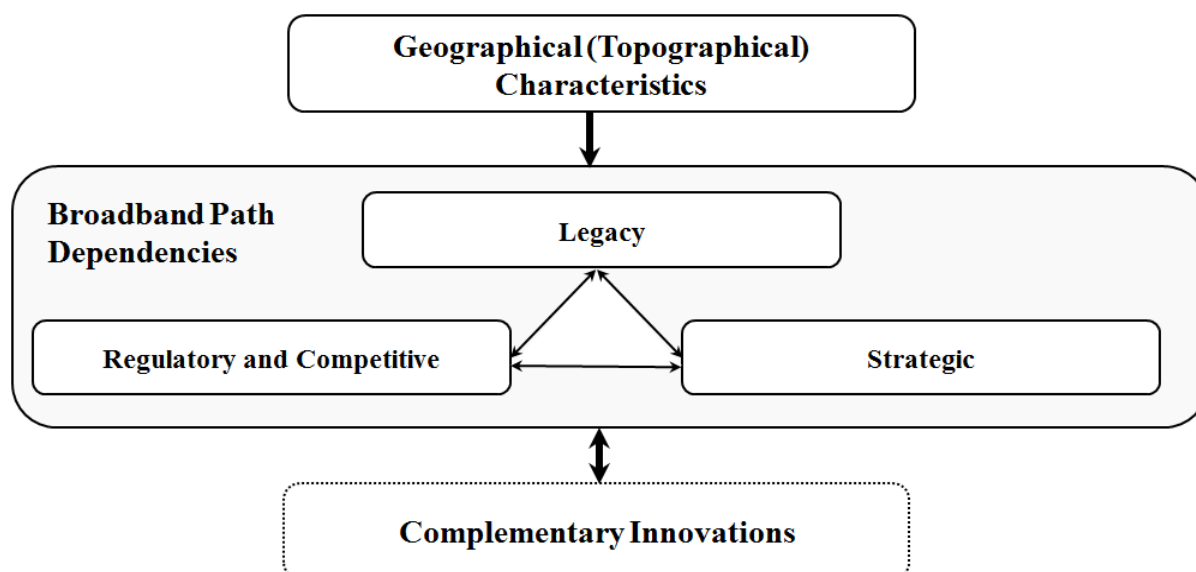


Figure 6: Network evolution and the path dependency triangle

Source: Derived from Florence School of Regulation (2017, pp. 26-31)

4.2 Technological neutrality and harmonization goals

Assuming that the public broadband targets as stipulated by the EC are desirable in terms of welfare, various NGA technologies appear to be feasible depending on what the targets actually are (Section 2). In achieving these goals, the CODE (recital 175) explicitly emphasizes the importance of infrastructure-based competition. However, pursuing the goal of “*incentivizing investment in high-speed broadband networks*” (CODE, recital 3) should not lead to the distortion of market outcomes through engaging in ‘winner-picking’, that is, explicitly favouring certain NGA technologies. Deviating from the principle of technological neutrality would instead require sound empirical evidence on the differential welfare effects of the available NGA technologies – evidence that is currently by and large not available.

Bertschek et al. (2016) provide a recent review of the economic impact of broadband infrastructure deployment and adoption on various economic outcome variables. Whereas the authors find the general result of a positive and statistically significant effect of basic broadband availability and adoption on either GDP or GDP growth in all reviewed country-level studies, they conclude with regards NGA broadband networks that “[*r*]eliable and broad evidence on economic impacts of high-speed wireline or wireless broadband infrastructure and adoption is still largely missing so far” (Bertschek et al., 2016, p. 224).

Only a handful of empirical studies explicitly include NGA-based broadband data. Fabling and Grimes (2016) estimate the productivity gains from NGA broadband adoption on employment using firm-level fibre data for New Zealand for the years 2010 and 2012. The authors find no significant effect of NGA broadband on employment on average, but only for firms making complementary investment in organizational capital. Bai (2017) examines the impact of different broadband speed levels using US county level data for the years from 2011-2014. The author assesses the differential impact on employment and finds a positive impact of broadband availability, but, compared to basic broadband, NGA broadband did not generate substantially greater positive effects on employment. Finally, Briglauer and Gugler (2018) employ EU27 panel data for the period 2003 to 2015. The authors estimate a significant but rather small effect of NGA broadband adoption over and above the effects of basic broadband on GDP. Their estimates suggest that a 1% increase in adoption leads to an incremental increase of about 0.004-0.005% of GDP with respect to FTTH/B broadband and to a 0.002-0.003% increase with respect to hybrid-fibre broadband.

Hence, to date, empirical evidence as regards the differential impact of various NGA broadband technologies is scant. The existing evidence indicates that the incremental benefits of NGA broadband might be overestimated and funding for ubiquitous coverage with FTTH/B is likely to lead to net societal losses.

Despite considerable growth rates over recent years in the use of FTTH/B broadband in some EU countries, there is no question that the vast majority of users are still utilizing hybrid NGA or older broadband technologies. Therefore, an unknown period will pass before the migration to an exclusively FTTH/B based broadband network is achieved. This implies that in the meantime efficient reuse must be made of the existing coaxial and copper cable networks. In view of substantial cost advantages and low current NGA take-up rates, existing and future second-life copper/coax technologies have, therefore, a crucial role to play in an efficient migration process. The market-driven speed of migration will depend on, among other factors, country specific characteristics (w.r.t. existing legacy infrastructures, population densities, topographical characteristics, and demand structures) and will balance benefits and costs in view of low take-up rates and further market uncertainties related to, for example, technological progress of future broadband access technologies. The market-driven migration approach will not least also depend on the scalability of hybrid-fibre access networks, that is, the extent of

non-recoverable costs in case of later moves towards FTTH/B networks (Vogelsang, 2013). Again, in a market-driven approach network operators will internalize this in their rationale ex ante decision making. In contrast, asymmetric information towards deployment costs makes it quite unlikely that a social planner is better informed about scalability in view of enormous heterogeneity in local access network topologies.

Another fundamental technological change and respective uncertainties will arrive with the roll-out of 5G mobile networks in the near future that will unify wireline and wireless infrastructures and require an optimal integration of transportation networks (e.g., roads, railway tracks, etc.) and access networks with different NGA architectures. Again, markets can be expected to better adjust to highly dynamic and uncertain market conditions.

The notion of efficient investment implies that real investment meets real demand (rather than maximizing investment per se) for a specific technology. Except in the case of clear market failure – which, as shown above, there is no apparent evidence available for – markets provide more efficient investment subject to the imperfect information available on future demand for high-bandwidth and technological progress. In order to incentivize investment in high-speed broadband infrastructure the CODE sets out three coverage objectives (Section 1) and legally defines “*very high capacity networks*” in Art. 2 (2) as follows:

“[V]ery high capacity network means an electronic communications network which either consists wholly of optical fiber elements at least up to the distribution point at the serving location or which is capable of delivering under usual peak-time conditions similar network performance in terms of available down- and uplink bandwidth, resilience, error-related parameters, and latency and its variation.”

As argued above, enhancing the deployment of very high capacity networks should not automatically favour a certain network architecture or access technology unless there is considerable and sound evidence of its comparative economic advantages. Although the CODE does not explicitly refer to certain NGA technologies as being particularly desirable, in several places (e.g., recital 13 and Art. 2 (2)) it is suggested that FTTH/B connections are to be treated as a preferential deployment target. However, subordinating technological neutrality to the dominant goal of deployment and connectivity targets, as foreseen in Art. 3 (3) lit c, is so far not supported by sufficiently convincing empirical evidence. This has been pointed out above and is summarized similarly in Florence School of Regulation (2016, p. 4):

“As for targets specified in terms of extended coverage of ultra-fast broadband technologies, we can conclude that the existing evidence is not sufficient to make a case for expressing a preference across the board for FTTH solutions. To clearly support the view that an extension of ultra-fast broadband targets would be justified, it would be necessary to find evidence either of the fact that significant positive externalities are not reflected in the current level of demand for ultra-fast broadband, so that there is a wedge between social goals and individual choices, or that a sufficient willingness to pay exists that is not met by private demand. The available empirical evidence does not confirm either of these elements.”

As shown in Section 3, the adoption and coverage of NGA broadband technologies exhibit substantial heterogeneity, in particular among western, eastern and northern European Member States. This is at odds with achieving the goals of policy harmonization that are strongly emphasized in the CODE, which aim to “*deliver conditions for a true single market by tackling regulatory fragmentation ... and consistent application of the rules*” (recital 3).¹⁷ Applying the same rules to the same conditions is of course reasonable but harmonization must not become a goal in and of itself that ignores the empirical market conditions and specific characteristics of individual Member States such as high availability of ducts (favouring ceteris paribus FTTH/B deployment) or a high number of street cabinets (favouring ceteris paribus FTTC deployment). As a consequence, pushing homogenous coverage and adoption targets and/or specific NGA scenarios inherently conflicts with heterogeneous situations in the Member States and is likely to result in a mechanism that yields inefficient outcomes.

Moreover, harmonized rules and targets not only likely lead to inefficiencies in view of heterogeneous market conditions, but also in view of typically substantial asymmetric information as regards actual demand and deployment costs in funded areas. Briglauer et al. (2016) show that the current funding practice based on fixed ex ante targets is inefficient given the uncertainty about future returns on NGA broadband services and the public authorities’ incomplete information about the costs of the network provider. The authors suggest delegating the choice of the network expansion to the typically much better informed network operator based on simple linear profit-sharing contracts.

¹⁷ Briglauer and Cambini (2018) empirically investigate the impact of the so-called ‘unbundling price’ that has represented the core access obligation in regulating broadband markets in the EU. The authors find that the regulatory instrument is effective in countries with a well-established first generation infrastructure, but ineffective in the group of Eastern European countries which exhibit low quality legacy networks. The authors conclude that the underlying heterogeneity casts doubt on a harmonized access regulation policy.

In summary: in the context of public policies for broadband, technology neutrality constitutes a proposition which, depending on the specification of the broadband target, ensures that the set of access technologies capable of delivering the broadband target is not unduly restricted. If meeting the pre-specified broadband targets cannot be ensured through a purely market-driven basis, an economically desirable solution should neither favour nor discriminate against a single or a set of specific access technologies that are technically capable of delivering the target. Technology neutrality should not, however, be erroneously equated with symmetric or identical subsidies for all available broadband access technologies in cases of (multiple) parallel access infrastructures.¹⁸

4.3 Public targets, universal service obligations and fixed-mobile integration

In the EU, the set of public policy instruments for stimulating broadband deployment is diverse and ranges from sector-specific regulations to measures that are largely motivated by industrial policy objectives. However, when considering the issue of ubiquitous access to high-speed (fixed and mobile) broadband access, the relevant set of instruments narrows. Incentivizing the roll-out of broadband via sector-specific access regulations is not an option in those areas where the roll-out of desired broadband infrastructures would not be viable (Briglaue and Cambini, 2017). Although sector-specific universal service regulations provide an alternative instrument that can be used to ensure ubiquitous broadband availability at socially desirable qualities and (uniform) price levels, this type of intervention has traditionally been used to mitigate the negative effects of social exclusion that especially occur due to digital divides between urban and rural and remote areas. Corresponding policies may be used to address specific externality issues, and serve to realize distributional concerns with provisions for basic ‘safety net’ Internet connectivity.¹⁹ Although debates about broadband as a universal service are ongoing and several universal service regulations have already been implemented at the national level (Batura, 2016; Stocker and Whalley, 2017; 2018), common to all such regulations is that the

¹⁸ This is in keeping with the stance taken by the EC in 1999, namely: “*This principle does not mean that all communications infrastructures should be regulated in an identical manner*” (European Commission, 1999, p. 14). They continue “[...] *regulatory measures might need to be taken on the basis of specific network or product technologies*” (European Commission, 1999, p. 15).

¹⁹ Recital 194 of the CODE describes universal service as a “*safety net*”, before going on to note that “*functional Internet access*” provides a basis for participation in the digital economy and society (European Commission, 2016a, p. 86).

corresponding broadband targets deliver speeds that are way below the targets for high-speed broadband as specified by the EU. Targets for high-speed broadband substantially exceed safety net connectivity levels and are primarily driven by ambitious industrial policy objectives. Ideally, the latter are well-founded in terms of positive externalities.

Questions arise as to whether public policies should keep or abandon technological neutrality principles and prescribe specific technology choices. Section 2 has shown that broadband does not present a singular technological proposition but rather comprises an evolving range of heterogeneous access technologies that differ significantly in terms of their performance characteristics, capacity sharing, reliability and connectivity mode (i.e., fixed vs. mobile). Section 3 then described that existing network deployments vary considerably across different geographies and Section 4 presented an overview of the relevant path dependencies. In the presence of cost diversity and vastly diverse revenue potentials across but also within EU Member States, the economics of broadband roll-out vary accordingly and are dynamically changing. For example, significant and ongoing technological advances in second-life copper/coax technologies and subsequently enhanced performance capabilities lead to a situation in which the incremental costs as well as the benefits of different migration scenarios may be changing rapidly. Absent empirical evidence that could inform and guide public policies, the *ex-ante* imposition of broadband targets that stipulate specific broadband performance targets or technology choices are, from an economic perspective, *ad hoc* and likely inefficient.

Even if public broadband policies do not prescribe specific technology choices and rather impose technology-agnostic performance targets, direct implications for the set of technically eligible access technologies can be derived. While uniform performance targets at least partially neglect the heterogeneity of status quo deployments and corresponding path dependencies, the higher and more stringent the performance targets are defined the narrower the set of eligible access technologies (Stocker and Whalley, 2017, p. 24). Ambitious performance targets thus lead automatically to the exclusion of those access technologies that are technically incapable of delivering the targets. Interestingly in this respect, as was shown in Section 3, persistently low take-up rates indicate that low adoption on the demand side actually represents a major problem. This may indicate that overly ambitious and non-coordinated broadband investments may fail to deliver desired welfare gains. In fact, consumer experience and the marginal benefits of additional bandwidth may decline steeply (Stocker and Whalley, 2018; Bauer et al., 2015).

It is not surprising that ‘killer applications’, which rely on gigabit connections (Kenny, 2015, pp. 16-17), do not yet exist.

This may raise some specific problems. Corresponding proactive strategies may aim to address ‘vertical’ coordination problems between different but complementary innovations and related ‘chicken-and-egg’-like situations.²⁰ Broadband policies may aim to resolve such coordination problems on the basis of proactive and ambitious broadband investments to provide a functional platform ecosystem that facilitates and fosters downstream innovations and are capable of flexibly adapting to a rapidly evolving set of demands. Despite uncertainties regarding a future (unknowable) set of relevant applications and the welfare gains attached to them, proactive public policy targets may be derived from the demands of an existing or anticipated set of (politically or socially) desirable content and application services. Similarly, targets may reflect political promises to facilitate the ubiquitous delivery of specific industry applications such as innovative IoT-related applications like automated connected cars or eHealth (European Commission, 2016a, Recitals 12; 103). From an economic perspective, application-specific broadband targets conflict with market-driven innovation paths and are, as a result, likely to be inefficient. Rather, they reflect the dominant narratives underlying specific applications or policymakers’ specific visions of how the ecosystem should look like rather than the actual welfare gains sought.

Closely related to the issues discussed above are more generic problems. For example, considering the tremendously dynamic and heterogeneous cost and demand side conditions across as well as within EU Member States, problems of asymmetric information may arise. It is rather unlikely that a social planner is better informed about the technological upgradability and economic scalability of specific access technologies than broadband providers (Briglauer et al., 2016). Broadband targets may further reflect the outcomes of the games being played by different and often competing stakeholders (Stocker and Whalley, 2017). Similarly, the promise of public funding may have the unintended consequence of stifling or even crowding out (private sector) investment as broadband providers may be incentivized to play a ‘waiting game’ to strategically increase the share of public funding they receive (Valletti, 2016, p. 15).

²⁰ For a more generic discussion of relevant coordination problems in the context of complementary innovations, see Bauer and Knieps (2018, pp. 174-175).

Lastly, broadband targets may raise multi-faceted coordination problems that arise in the course of infrastructure-sharing. Policies that can appropriately address these coordination problems are essential for facilitating the cost-efficient delivery of broadband targets. More specifically, there are several types of cost synergies that can only be exploited through coordinated policy approaches. The (re)use of legacy network infrastructures as well as access to passive infrastructure elements constitute essential components in the cost-efficient path towards achieving broadband targets. In addition to using existing infrastructure elements of telecommunications and CATV networks, additional possibilities for infrastructure-sharing with traditional utility and transportation networks should be exploited.²¹

Furthermore, cost synergies between fixed and 5G become increasingly important in the context of fixed-wireless convergence (Body of European Regulators for Electronic Communications, 2017), though the benefits of coordination between fixed and mobile investment strategies need to be recognized and realised. Sharing fibre-based backhaul infrastructures for 5G delivery should be used to ensure cost efficiency (Ofcom, 2018, pp. 25-27). That being said, path dependencies shape the degree to which sharing potentials exist and imply a geographical diversity of sharing potentials and coordination problems. While corresponding cost advantages can be rather conveniently exploited in those areas where the footprints of fibre and mobile overlap (e.g. in urban areas), in rural or remote ‘mobile only’ areas dual but integrated public policy approaches need to address more complex coordination problems to leverage the cost synergies associated with integrated roll-out strategies of fixed and mobile broadband infrastructures.

4.4 Generic policy guidance for technological neutrality decision making

Based on the discussion in the previous sections, Figure 7 provides a summarizing flow chart that could guide policy decision making regarding the role and economic desirability of technological neutrality. The flow chart figure is divided into several phases reflecting policy making beginning with the initial target setting phase representing political outcomes at both the EU and national level. Broadband targets, as introduced by public policies for high-speed broadband, focus on access technologies that are capable of meeting (expected) future demands.

²¹ See the comprehensive study by Godlovitch et al. (2018). Among other things, they provide an overview of the various infrastructure sharing models and also describe case studies in the EU.

The relevant dimensions of exogenously defined targets, that is, those determined outside the relevant markets, automatically narrow the eligible set of access technologies, and thus to a certain extent also the scope of technological neutrality.²² Given these targets and the de facto scope of technological neutrality, policy makers should then assess the relevance of externalities underlying eligible access technologies, the extent of path dependencies, scalability of hybrid NGA networks and market uncertainties as well as of local heterogeneities. Regarding the latter, situations vary significantly depending on the availability and technological state of existing infrastructures and their upgradability. As a result, costs vary across different regions and heterogeneous path dependencies may require geographically differentiated roll-out scenarios (e.g., favouring FTTH/B deployment in low cost urban areas only).

The final decision to abandon or keep technological neutrality might also be indicative of the need to re-specify the initial set of eligible access technologies. In cases where empirical evidence suggests ex post that externalities are, in fact, minor, this also calls into question the need to have exogenously and pre-defined policy targets in the first place. In contrast, the absence of externalities, and hence absence of market failure, suggests letting quality parameters be endogenously defined by competitive market dynamics. It is worth noting that although the binary nature (Yes/No) of the individual decision points is simplistic, it points to the need for rationale decision making grounded on sufficient empirical evidence.

²² There are many dimensions that describe the stringency of broadband targets, for example, data rates (i.e., ‘speeds’), reliability, symmetry of up- and downstream data rates or jitter and latency.

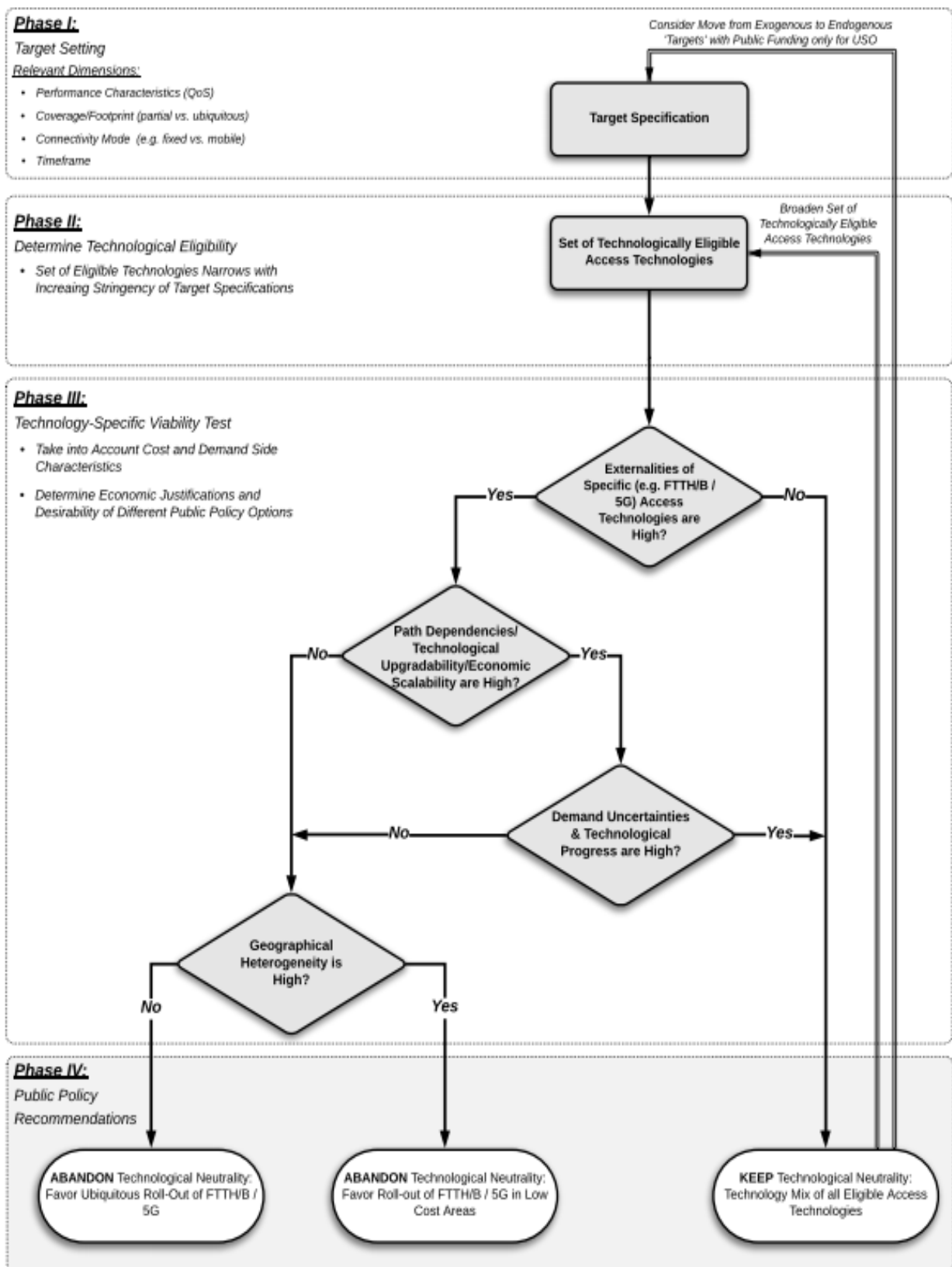


Figure 7: Technological neutrality policy-making process

5 Conclusions

This paper has focused on technological neutrality within the context of the policy targets that the EU has adopted. These targets, initially outlined in 2010 and subsequently updated in 2016, reflect a rather ‘simple’ objective: to ensure that everyone has access to high-speed Internet. Not only will this widespread access maximise the socio-economic benefits that will occur, but it will also encourage innovative activity across many different sectors.

However, achieving this ‘simple’ objective is not straightforward. First of all, there is a need to encourage investment. While it is tempting to focus on ‘new’ investment, which expands networks into new areas or reflects new technological developments like 5G, it is also necessary to remember that investment is needed to upgrade existing infrastructures. While the promise of 5G may be seductive, it will be several years before it is widely available with the consequence that upgrading existing infrastructures will play a key role in the coming years in achieving the targets articulated by the EU.

The upgrade of existing infrastructures, and perhaps their expansion, will differ between Member States. As we have shown, broadband infrastructures differ between Member States, reflecting the complex and dynamic interaction that occurs between a series of path dependencies subject to substantial heterogeneity. This complex and dynamic interaction limits the ability of the EU to mandate a common approach, as, quite simply, circumstances are different between Member States to such an extent that adopting a ‘one solution fits all’ approach will be sub-optimal. Thus, Member States need flexibility to implement initiatives, appropriate to their own specific context, which enables them to achieve the objectives set by the EU. This, in turn, goes against setting precise pan-EU targets such as specific speeds or the availability of certain technologies by some date in the near future. Most of the national broadband plans in Member States, however, directly adopt EU targets, with only a handful of Member States setting coverage goals below 100% (European Commission, 2017, p. 40).

Under the current market conditions, the key role to be played by technological neutrality is achieving the objectives but not prescribing the means of doing so. Having said this, technological neutrality is challenged by objectives favouring FTTH/B based gigabit connectivity and 5G which directly attentions towards specific technologies. In other words, implicit within the targets is the need for an underlying infrastructure that contains a largest possible proportion of fibre. With respect to 5G, Member States will ‘naturally’ gain an

extensive fibre infrastructure as this underpins the (smaller and more numerous) cell sites that are required as this new generation of wireless technologies is adopted. It is currently unclear which NGA architecture is best suited in terms of optimal migration paths and fixed-mobile integration in local access networks. The latter remain subject to high market uncertainties and asymmetric information towards deployment costs makes it quite unlikely that a social planner is better informed than market participants. Against this background, public intervention in terms of picking certain technologies as ‘winners’ only becomes economically justified from a welfare perspective, if market-driven network evolution demonstrably yields inferior market outcomes.

Notwithstanding the improvements in speed and other quality parameters that have occurred in recent years, those Member States that rely on copper and cable-based networks for broadband access are faced with a dilemma: should operators continue with implementing technological improvements to squeeze ever more out of their existing legacy infrastructures, or should they be encouraged to include ever more fibre in their networks and set corresponding policy targets? Our analysis has identified the series of key factors, with their interdependencies guiding a rationale decision making process. These key factors are

- extent of externalities related to FTTH/B / 5G deployment;
- extent of legacy-based path dependencies and scalability of hybrid NGA infrastructure;
- the extent of technological and demand side market uncertainties; and,
- the extent of market heterogeneities within and across Member States.

Future research should provide reliable empirical evidence on the relevance of each of these key factors.

If Member States want to incentivise operators, then technological neutrality, which does not specify how targets should be achieved, is arguably an attractive way forward. It is, however, problematic to implement when the EU on the one hand and national politicians on the other, talk about specific technologies (e.g., 5G) or speeds (as exemplified by the use of terms like ‘Gigabit society’). Such discussions promote a certain technological solution to achieve policy objectives, thereby suggesting that the role of technological neutrality is likely to be de facto limited as long as the EU remains attracted and committed to such targets.

References

- Accenture (2017). Smart Cities: How 5G Can Help Municipalities Become Vibrant Smart Cities, available at: <https://www.accenture.com>.
- Adtran (2018). 5G and FTTH: A Symbiotic Relationship, White Paper, February, available at: <https://www.adtran.com>.
- Ai, Y., Peng, M. & Zhang, K. (2018). Edge Computing Technologies for Internet of Things: A Primer. *Digital Communications and Networks* 4(2), 77-86.
- Arthur, W.B. (1989). Competing Technologies and Lock-in by Historical Small Events. *The Economic Journal* 99(394), 116-131.
- Bai, Y. (2017). The Faster, the Better? The Impact of Internet Speed on Employment. *Information Economics and Policy* 40, 21-25.
- Batura, O. (2016). *Universal Service in WTO and EU Law – Liberalisation and Social Regulation in Telecommunications*, Springer: Heidelberg, Germany.
- Bauer, J.M. & Knieps, G. (2018). Complementary Innovation and Network Neutrality. *Telecommunications Policy* 42(2), 172-183.
- Bauer, S., Lehr, W.H., & Hung, S. (2015). Gigabit Broadband, Interconnection, Propositions and the Challenge of Managing Expectations. *TPRC 43: The 43rd Research Conference on Communication, Information and Internet Policy Paper*. Available at SSRN: <https://ssrn.com/abstract=2586805> or <http://dx.doi.org/10.2139/ssrn.2586805>.
- Begen, A.C. & Timmerer, C. (2017). Adaptive Streaming of Traditional and Omnidirectional Media. *ACM SIGCOMM Tutorial* 21-25 August, Los Angeles, CA.
- Bertschek, I., Briglauer, W., Hüscherlath, K., Kauf, B. & Niebel, T. (2016). The Economic Impacts of Broadband Internet: A Survey. *Review of Network Economics* 14(4), 201-227.
- Body of European Regulators for Electronic Communications (2017). *BEREC Report on the convergence of fixed and mobile networks*, 6 October, BoR (17) 187, Brussels.
- Bresnahan, T.F. & Trajtenberg, M. (1995). General purpose technologies: Engines of growth?. *Journal of Econometrics* 65(1), 83-108.
- Briglauer, W. (2014), The Impact of Regulation and Competition on the Adoption of Fiber-based Broadband Services: Recent Evidence from the European Union Member States, *Journal of Regulatory Economics* 46, 51-79.
- Briglauer, W. & Gugler, K. (2013). The deployment and penetration of high-speed fiber networks and services: Why are EU member states lagging behind? *Telecommunications Policy* 37(10), 819-835.

- Briglauer, W. & Cambini, C. (2017). The Role of Regulation in Incentivizing Investment in New Communications Infrastructure, Report prepared for Deutsche Telekom, available at: <http://ftp.zew.de/pub/zew-docs/gutachten/BriglauerCambiniDeutscheTelekomApril2017.pdf>.
- Briglauer, W. & Gugler, K. (2018). Go for Gigabit? First Evidence on Economic Benefits of (Ultra-)Fast Broadband Technologies in Europe, ZEW Discussion Paper No. 18-020.
- Briglauer, W., Holzleitner, C., & Vogelsang, I. (2016). The Need For More Efficient Public Funding of New Communications Infrastructure in EU Member States, *Information Economics and Policy* 36, 26-35.
- Briglauer, W., Camarda, E. & Vogelsang, I. (2017). Path Dependencies versus Efficiencies in Regulation: Evidence from 'Old' and 'New' Broadband Markets in the EU, working paper, available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3050661.
- Briglauer, W., & Cambini, C. (2018). Promoting Consumer Migration to New Communications Technology: Does Regulation Affect the Digital Gap?, *Industrial and Corporate Change*, forthcoming.
- Cave, M., & Feasey, R. (2017). Policy towards competition in high-speed broadband in Europe, in an age of vertical and horizontal integration and oligopolies. Project report, Centre on Regulation in Europe.
- Cave, M. & Shortall, T. (2016). Technological neutrality, targets, and competition objectives. In: *The Future of Broadband Policy: Public Targets and Private Investments*, Florence School of Regulation, Florence.
- Cisco (2018). SKBroadband Sets Speed Record in Korea with Its Gigabit Broadband Service Powered by Cisco. Press Release, 5 June, available at: <https://newsroom.cisco.com>
- Claffy, K., Huston, G. & Clark, D.D. (2018). Workshop on Internet Economics (WIE2017) Final Report. *ACM SIGCOMM Computer Communication Review*, forthcoming.
- Clark, D.D., Lehr, W., Bauer, S., Faratin, P., Sami, R. & Wroclawski, J. (2006). Overlay Networks and the Future of the Internet. *Communications & Strategies* 63(3), 109-129.
- Coomans, W., Moraes, R., Hooghe, K., Duque, A., Galaro, J., Timmers, M., van Wijngaarden, A., Guenach, M. & Maes, J. (2015). XG-fast: the 5th generation broadband, *IEEE Communications Magazine* 53(12), 83-88.
- Crandall, R. W., Eisenach, J. A., & Ingraham, A. T. (2013). The long-run effects of copper-loop unbundling and the implications for fiber. *Telecommunications Policy* 37(4), 262-281.
- David, P.A. (1985). Clio and the economics of QWERTY. *American Economic Review* 75(2), 332-337.
- David, P.A. (2007). Path Dependence: A Foundational Concept for Historical Social Science. *Cliometrica* 1(2), 91-114.

- DotEcon and Axon (2018). Study on Implications of 5G Deployment on Future Business Models. No BERECA/2017/02/NP3, 14 March, A Report by DotEcon Ltd and Axon Partners Group, BoR (18) 23, Brussels.
- European Commission (1999). Towards a New Framework for Electronic Communications Infrastructure and Associated Services, The 1999 Communications Review, COM(1999) 539final, Brussels.
- European Commission (2009). Directive 2002/21/EC on a common regulatory framework for electronic communications networks and services (Framework Directive) as amended by Directive 2009/140/EC and Regulation 544/2009, Brussels.
- European Commission (2010). A Digital Agenda for Europe, COM (2010) 245, Brussels.
- European Commission (2014). Commission Recommendation of 9 October 2014 on relevant product and service markets within the electronic communications sector susceptible to ex ante regulation in accordance with Directive 2002/21/EC on a common regulatory framework for electronic communications networks and services, Brussels.
- European Commission (2016a). Proposal for a Directive of the European Parliament and of the Council establishing the European Electronic Communications Code (Recast), COM/2016/0590 final - 2016/0288 (COD), Brussels.
- European Commission (2016b). Connectivity for a Competitive Digital Single Market – Towards a European Gigabit Society, SWD (2016) 300 final, Brussels.
- European Commission (2016c). 5G for Europe: An Action Plan, Communication from The Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2016) 588 final, Brussels.
- European Commission (2017). Europe's Digital Progress Report 2017, Brussels, available at: <https://ec.europa.eu/digital-single-market/en/news/europes-digital-progress-report-2017>.
- European Commission (2018). Digital Single Market: EU negotiators reach a political agreement to update the EU's telecoms rules, Press Release, 6 June, Brussels.
- Fabling, R., & Grimes, A. (2016). Picking up speed: Does ultrafast broadband increase firm productivity?. Motu working paper 16-22.
- Finnie, G. (2012). FTTH in Europe: Forecasts & prognosis, 2010-2015. White paper prepared by Heavy Reading on behalf of FTTH Council Europe.
- Florence School of Regulation (2016). *The Future of Broadband Policy: Public Targets and Private Investments*, A Report by the Florence School of Regulation Communications and Media for the Public Consultation on the Needs for Internet Speed and Quality Beyond 2020, Florence.

- Florence School of Regulation (2017). *The Future of Broadband Policy, Part 2: Technological Neutrality, Path Dependency and Public Financing*, A Report By The Florence School Of Regulation, Communications & Media Area, Florence.
- FTTH Council Europe (2018). *FTTH Handbook*, Edition 8, D&O Committee, revision date: 13 February 2018, available at: <http://www.ftthcouncil.eu>.
- Godlovitch, I., Henseler-Unger, I. & Stumpf, U. (2015). *Competition & investment: An analysis of the drivers of superfast broadband. WIK-Consult, study for OFCOM*. Bad Honnef.
- Godlovitch, I., Plueckebaum, T., Kroon, P., Wissner, M., Batura, O., Hausemer, P., Vincze, M., Held, C., Schäfer, S. & Juskevicius, R. (2018). *Study on Implementation and monitoring of measures under Directive 61/2014 Cost Reduction Directive. SMART 2015/0066, Final Report*, A study prepared for the European Commission DG Communications Networks, Content & Technology, European Commission, Brussels.
- Grajek, M. & Kretschmer, T. (2009). Usage and diffusion of cellular telephony, 1998-2004. *International Journal of Industrial Organization* 27, 238-249.
- Huston, G. (2017). *The Rise and Rise of Content Distribution Networks*. Presentation at the 8th Workshop on Internet Economics (WIE 2017), 13-14 December, San Diego, CA.
- Kenny, R. (2015). *Exploring the costs and benefits of FTTH in the UK*, March, Nesta, London.
- Knieps, G. (2017). Internet of Things and the Economics of Smart Sustainable Cities. *Competition and Regulation in Network Industries* 18 (1-2), 115-131.
- Knieps, G. & Zenhäusern, P. (2015). Broadband Network Evolution and Path Dependency. *Competition and Regulation in Network Industries* 16(4), 335-353.
- Linthicum, D. (n.d.). *Edge Computing vs. Fog Computing: Definitions and Enterprise Uses*, available at: www.cisco.com.
- Littmann, D., Wigginton, C., Wilson, P., Haan, B. & Fritz, J. (2017). *Communications Infrastructure Upgrade: The Need for Deep Fiber*, available at: <https://www2.deloitte.com>.
- OECD (2008). *Broadband and the Economy. Ministerial Background Report*, DSTI/ICCP/IE(2007)3/FINAL, available at: www.oecd.org.
- Ofcom (2018). *Enabling 5G in the UK*, 9 March, OFCOM, London.
- Parcu, P. L. (2016). *Policy suggestions on fast and ultra-fast broadband targets for the European Commission*, In: *The Future of Broadband Policy: Public Targets and Private Investments*, A Report by the Florence School of Regulation Communications and Media, Florence.
- Schultze, S.J. & Whitt, R.S. (2016). The Internet as a complex layered system, in: Bauer, J.M. & Latzer, M. (eds.) *Handbook on The Economics of The Internet*, Edward Elgar: Cheltenham, 55-71.

- Stocker, V., Smaragdakis, G., Lehr, W. H., & Bauer, S. (2017). The growing complexity of content delivery networks: Challenges and implications for the Internet ecosystem. *Telecommunications Policy* 41(10), 1003-1016.
- Stocker, V. & Whalley, J. (2017). Who Replies to Consultations, and What Do They Say? The Case of Broadband Universal Service in the UK. Paper presented at the 28th European Regional ITS Conference, Passau, Germany, 30 July-2 August.
- Stocker, V. & Whalley, J. (2018). Speed isn't everything: A multi-criteria analysis of the broadband consumer experience in the UK. *Telecommunications Policy* 42(1), 1-14.
- Tanenbaum, A.S. & Wetherall, D.J. (2011). *Computer Networking*, 5th edition, Boston et al.: Prentice Hall.
- Timmers, M., Zhao, R., Mau, J. & Salgado, J. (2018). Migrating from Copper to Fibre: The Telco Perspective. A White Paper by the Deployment & Operations Committee, available at: <http://www.ftthcouncil.eu>.
- Valdar, A. (2006). *Understanding Telecommunication Networks*, Series 52, London: The Institution of Engineering and Technology.
- Valletti, T. (2016). *The role of broadband targets*. In: The Future of Broadband Policy: Public Targets and Private Investments, A Report by the Florence School of Regulation Communications and Media for the Public Consultation on the Needs for Internet Speed and Quality Beyond 2020, Florence.
- Vogelsang, I. (2013). The Endgame of Telecommunications Policy? A Survey. *Review of Economics/Jahrbuch für Wirtschaftswissenschaften* 64(3), 193-269.
- Wannstrom, J. (2013). *LTE-Advanced for 3GPP*, available at: <http://www.3gpp.org/technologies/keywords/acronyms/97-lte-advanced>.
- Whalley, J. & Curwen, P. (2017). From phones to football: The changing strategic focus of BT. *Telematics & Informatics* 34(5), 798-809.
- Yoo, C.S. (2016). Modularity theory and Internet Regulation. *University of Illinois Law Review* 2016(1), 1-62.
- Zarnekow, R., Wulf, J. & von Bornstaedt, F. (2013). *Internetwirtschaft: Das Geschäft des Datentransports im Internet*, Berlin and Heidelberg: Springer Gabler Verlag.
- ZetaCast (2012). Technical Evolution of the DTT Platform, An independent report by ZetaCast, commissioned by Ofcom, Version 1.3, 28 January.
- Zhao, R., Fischer, W., Aker, E. & Rigby, P. (2014). White Paper: Broadband Access Technologies. A White Paper by the Deployment & Operations Committee, FTTH Council Europe, available at: <http://www.ftthcouncil.eu>.