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Paper

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

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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 to incentivise investment in high-speed broadband networks have been set 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 might implicitly favour specific technologies, especially when gigabit targets are defined, the technological choices that occur within individual Member States 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. Adopting an ecosystem perspective, we propose a conceptual framework that identifies the key factors associated with technological neutrality and informs a rational decision-making process.

1 Introduction

The European Commission (EC) published its proposal for establishing the European Electronic Communications Code on 14 September 2016 (European Commission, 2016a, hereinafter the ‘CODE’). Agreement on the proposal was reached in June 2018 (European Commission, 2018), with the CODE substantially revising the existing regulatory framework. In fact, one of its core elements are a series of goals to incentivize investment in new high-speed broadband infrastructure. In view of the high levels of investment required, appropriate investment incentives play an essential role in the migration towards achieving the broadband targets that have been set. When considering the relevant market developments to date in most European Union (EU) Member States, specifically the declining communications revenues and actual coverage and adoption patterns (European Commission, 2017), it seems questionable whether the existing market conditions will yield ubiquitous coverage with high-speed broadband infrastructures as well as 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 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; 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 major transport paths; and,

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[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 alternative technological options for high-speed broadband deployments do 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 profitable, 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: we 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*

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[2] See Briglauer and Cambini (2017) who discuss the impact of various regulatory regimes on incentivizing investment in new broadband infrastructure.

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

> *neither imposes nor discriminates in favour of the use of a particular type of technology, does not 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, we adopt an ecosystem perspective taking into account past market developments in EU Member States and resulting path dependencies but also (complementary) innovations in the ecosystem.

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 guiding a rational decision-making for broadband policies. 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 Internet via narrowband dial-up modems (see, e.g., 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 technologies[4] 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 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. These 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, FTTEx) 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, twisted-pair copper lines typically cover the last (several hundred) meters and connect street cabinets to the customer premises. Fibre to the distribution point (FTTDp) supported by VDSL/G.fast is another recent hybrid copper-fibre

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[4] xDSL refers to various 'Digital Subscriber Line' technologies, which provide Internet access by transmitting data over the twisted-pair copper lines of the legacy telephony network's access loop. "Very-high-bit-rate digital subscriber line" (VDSL), VDSL2 and VDSL vectoring are currently the most advanced DSL-based technologies.

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

broadband access technology. From an architectural point of view, FTTDp 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. Upcoming technological innovations, XG.fast in particular, are 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 it is feasible to completely eliminate copper lines, even in-house, full-fiberisation is achieved. In these cases, each subscriber can be connected by a fibre access line, a system referred to as fibre to the home (FTTH). FTTH is said to be ‘future proof’ as the capabilities of access technologies are limited by components 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 and topology, 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 – the community antenna television (CATV) network. 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, the underlying architectural design and network topology lead 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, transmission capacity is shared between all active users that are connected via the same network tree. Especially during peak times, this might cause significant performance reductions such as, for example, reduced data rates. In addition, HFC networks are optimized asymmetrically for downstream usage. Thus, upstream capacity is 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] In the following, these technologies shall be subsumed under the heading of 'cable modem-based' broadband access.

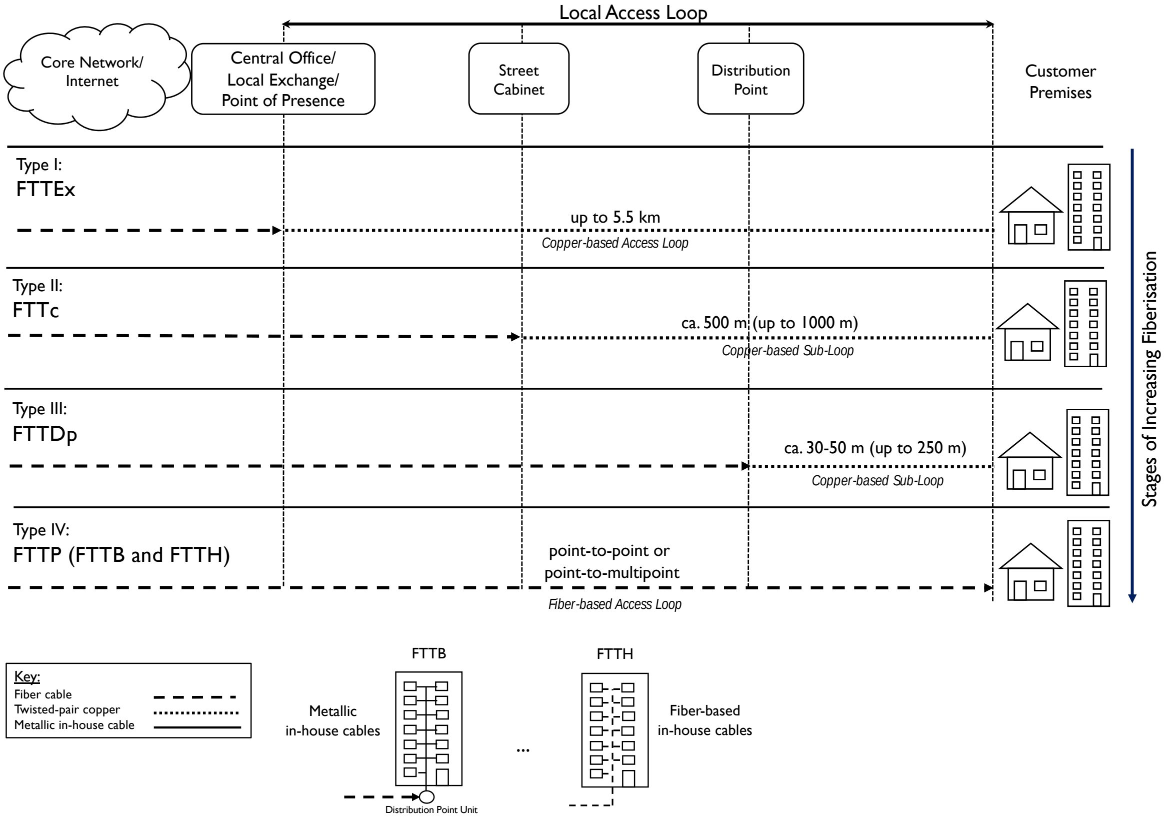

Figure 1: Relevant FTTx-based network architectures

Source: FTTH Council Europe, 2018, Figure 2 at p. 13 and pp. 12-14; Timmers et al., 2018, Figure 2 at p. 4 and pp. 4-5; Zhao et al., 2014, Figure 2 at p. 6 and pp. 6-7.

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[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).

Complementing fixed broadband access, 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 theoretical maximum data rates that are almost comparable to those provided via fixed-line hybrid-fibre NGA systems (e.g., Wannstrom, 2013). Even though corresponding technologies have been deployed in many Member States, the quality and stability of data transmission depends on a host of factors (e.g., weather conditions or the number of active users within a cell) and are susceptible to performance degradations that impair consumer experience. In its most recent market recommendation, the European Commission (2014, p. 22) considers 4G to be a viable substitute to wireline NGA broadband services in the medium term but currently is not yet a close enough substitute for fixed broadband in most consumer segments.

This, however, may change with further advances in mobile access technologies. 5G, in particular, is expected to yield significant increases in data rates and is providing the necessary wireless infrastructure basis facilitating ubiquitous and seamless mobility as well as 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 is capable of meeting the 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).

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

Significantly, at its core, 5G is a fibre-based technology. Thus, 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). In terms of optimal FTTx migration scenarios and fixed-mobile integration in access networks, however, these upcoming developments in the mobile sector also give rise to considerable technological uncertainties.[8]

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 facilitating the delivery of 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, FTTDp networks using XG.fast transmission technology could become a cost-efficient fibre backhaul for 5G networks (Coomans et al., 2015, p. 83).

3 Broadband in the EU: High Heterogeneity and Low Take-up Rates

Figure 2 shows the adoption of broadband services based on all available wireline broadband technologies. To a large extent broadband services are provided by CATV networks (including DOCSIS 3.0) or via DSL-based technologies (including FTTC/VDSL). Only in a few countries FTTH/B Internet connections make up a substantial proportion of the total connections. A comparison of Member States exhibits substantial heterogeneity as regards the use of access

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

technologies. In Belgium, for example, more than 50% of subscribed connections use the legacy infrastructure of the CATV 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, 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.

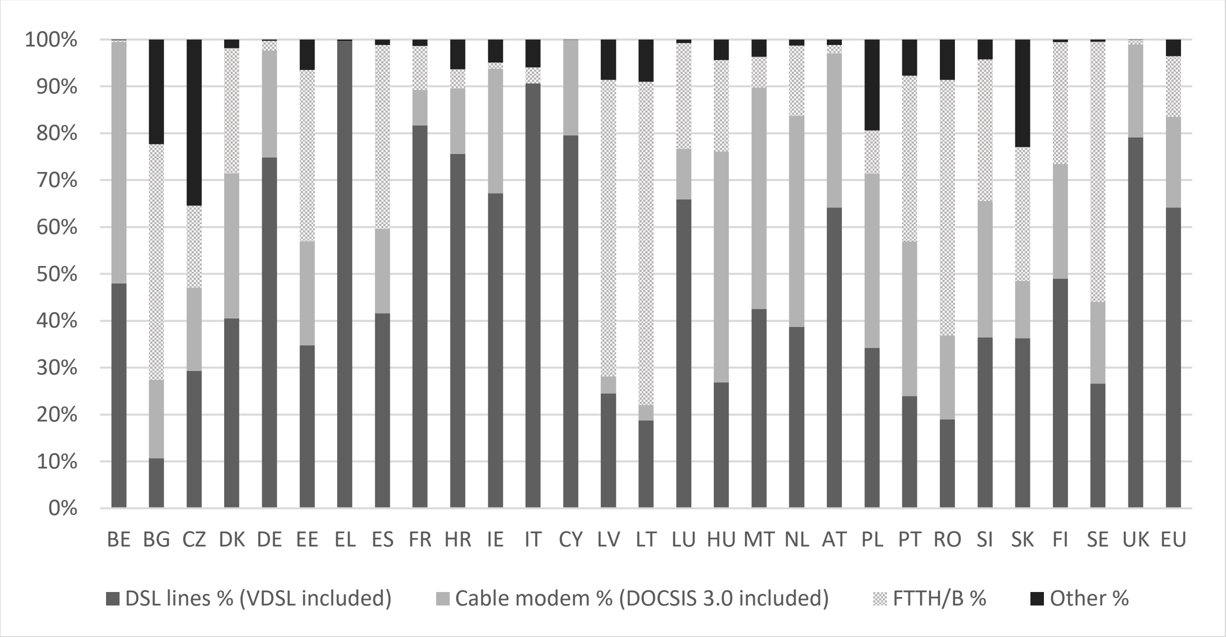

Figure 2: Technology market shares in fixed broadband subscriptions (July 2016)

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 role of local authorities and utility companies that have been strongly engaged in FTTH/B deployment activities in northern European countries (Godlovitch et al., 2015; Crandall et al., 2013, p. 274).

The comparatively good quality of the legacy-based telecommunications and CATV networks – specifically in terms of usability of existing ducts and ductworks and the number of distribution points – ensures technological upgradability via second-life hybrid NGA technologies in western European countries. FTTH/B investment would 'cannibalize' economic benefits from the first-generation broadband related services in those countries. In other words, upgrading first-generation broadband infrastructure with second-life copper/coax access technologies creates high opportunity costs associated with alternative investment in FTTH/B infrastructures that would have to be largely built anew. Due to the technological advances that have tremendously increased the capabilities of second-life access technologies, this 'replacement effect' has been further strengthened. At the same time, reusing and upgrading (high quality) legacy infrastructures has proven to be of high economic value (Coomans et al., 2015). Consequently, it is not surprising that in some of the largest western European countries existing FTTH/B deployment projects typically focus on only a small number of urban regions. In contrast, as legacy networks in eastern European countries typically exhibit lower qualities, technological upgradability is comparatively low. Not only does this lead to lower replacement effects, but also offers the opportunity of technological leapfrogging and to directly migrate to FTTH/B-based network deployments.

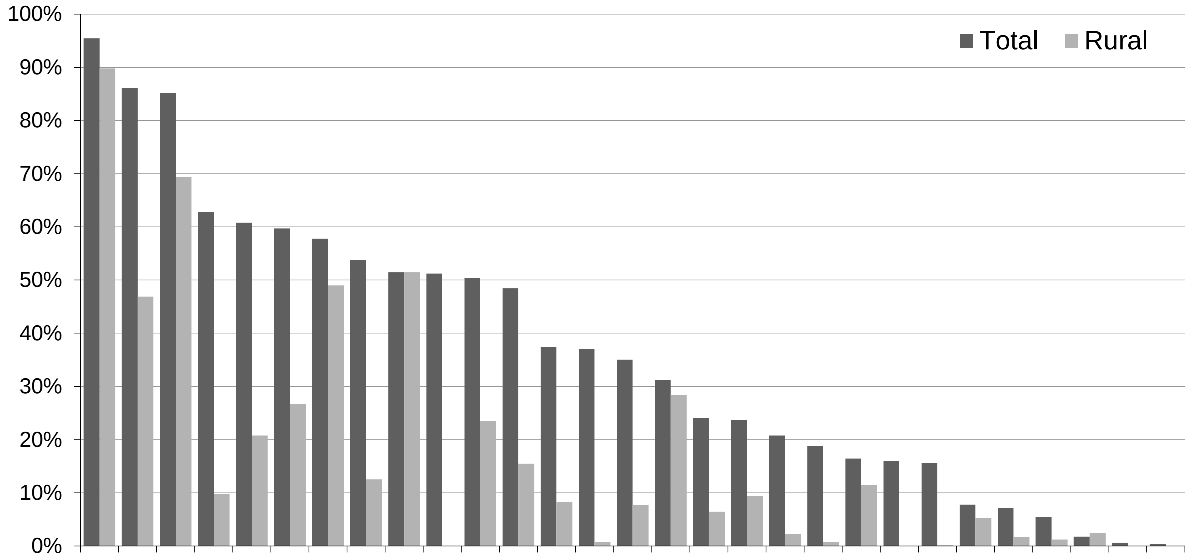

Figure 3: FTTH/B coverage (June 2016)

Source: European Commission (2017)

It is important to note though, 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 inter- and intra-country variation between rural and urban areas as regards FTTH/B and NGA coverage across and within EU Member States. The heterogeneity of legacy network deployments creates differences in their technological upgradability and economic scalability. That is to say, the migration towards achieving harmonized policy targets incurs costs. As demand structures and consumption patterns determine revenue potentials in different geographies, the economics of roll-out and, as a consequence, optimal migration paths likely differ. It is this heterogeneity related to differing demand and cost conditions which presents a clear limitation to the goal of harmonizing broadband deployment policies and targets.

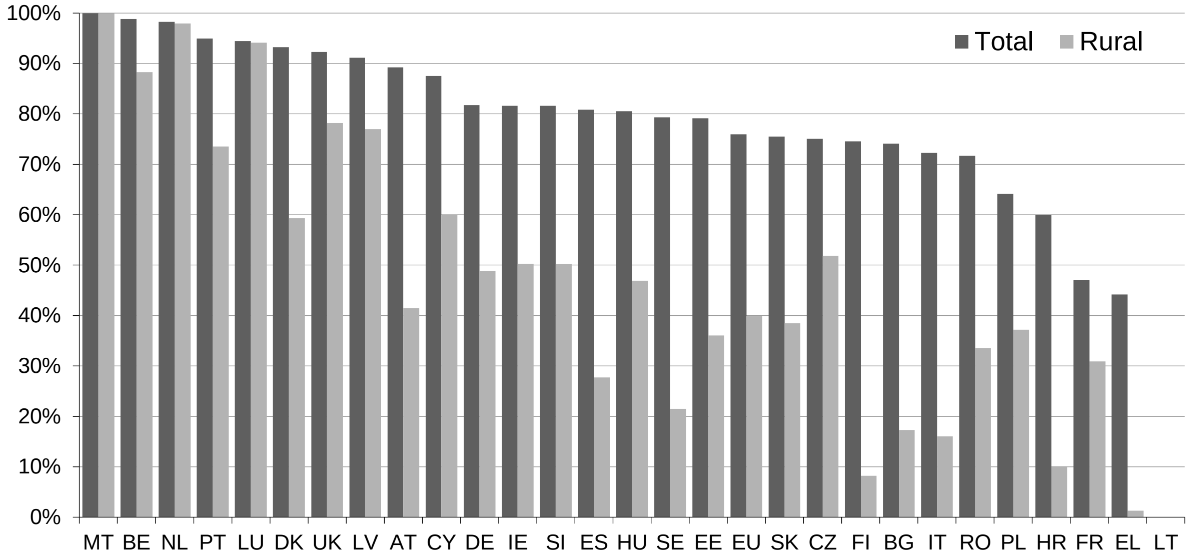

Figure 4: NGA coverage in rural areas and in total (June 2016)

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 not much willingness of consumers yet to migrate and subscribe to higher-capacity broadband products. While this helps to explain rather low NGA take-up rates, one could expect that consumers would decide to migrate if their perceived benefits of migration are significant and transparent enough (Grajek and Kretschmer, 2009; Briglauer, 2014). It needs to be noted that 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. Even more, low take-up rates indicate costly over-capacities diminishing expected profits and hence ex ante investment incentives.

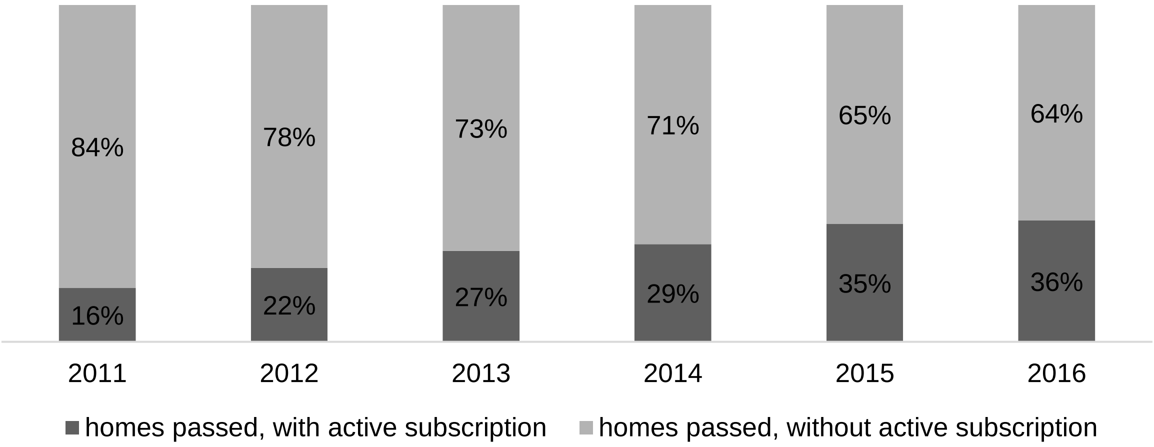

Figure 5: NGA take-up of broadband subscriptions as a % of all homes passed (EU level)

Source: European Commission (2017)

4 A critical assessment of technological neutrality and public policy targets

From an economic perspective, the imposition of public broadband targets is justified if they compensate for situations in which markets do not supply socially 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 gains remain unexploited due to suboptimal rates of migration towards FTTH/B or 5G networks.

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 accounting for 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 determining optimal migration paths 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.

Among others, Knieps and Zenhäusern (2015) emphasize the role of path dependencies in the context of broadband network evolution. They describe how path dependent network upgrading strategies prevent migration towards technologically superior fiber-based broadband access technologies. In the same context, a recent report by the Florence School of Regulation (2017, pp. 26-31) identifies and describes four dimensions of relevant path dependencies –

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[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).

geographical/legacy, competitive, regulatory, and strategic path dependencies. Drawing on this report and the explanations they provide, we adapt their categorization concept and explanations. Significantly, we extend their approach by placing a specific emphasis on the identification and explanation of the dynamic interdependencies between the different types of broadband-related path dependencies and – taking into consideration the role of complementary innovations – develop an ‘ecosystem perspective’. From this, valuable implications the design and assessment of public policies for broadband can be derived.

We start with a set of ‘invariable’ and thus exogenous factors related to geographical, especially topographical characteristics. These factors constitute a formative force in the evolution of the Internet ecosystem – they strongly impact on demand and cost conditions, and critically impact on the economics of broadband roll-out and market-driven 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 even though the latter are technologically superior. 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 be considered when analysing network evolution and also 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 infrastructures, rights of way and ducts,[10] have a strong influence on status quo broadband

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[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).

deployments – especially in terms of their availability, topology and configuration – and also significantly impact on optimal migration paths towards FTTH/B.

On the one hand, these path dependencies shape the technological upgradability as well as the economic scalability of existing broadband deployments and thus 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 the cost-efficient 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. In contrast, legacy path dependencies are less relevant in those areas where no first-generation 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 broadband 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 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 competition fundamentally rests on sector-specific access regulations.[11]

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[11] For discussions of broadband-related regulatory path dependencies, the reader is referred to Cave and Feasey (2017) and Knieps and Zenhäusern (2015). See Briglauer et al. (2017) for a recent quantitative investigation relating (inter alia) NGA broadband regulations to first-generation broadband regulations. Using EU level panel data, the authors find evidence supporting both that regulators pursue normative objectives as well as inefficiencies related to regulatory path dependence and bureaucracy goals of policy makers.

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. Thus, they significantly determine entrepreneurial investment incentives and therefore 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 (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 perspective to understand the investment decisions broadband providers are confronted with. In fact, due to the modularity of the Internet (e.g., Yoo, 2016; Schultze and Whitt, 2016), and the growing importance of complementary innovations (e.g., Bauer and Knieps, 2018), a broader ‘ecosystem perspective’ needs to be adopted to capture the complex set of interactions between the many components that shape incentives for broadband investments. Specifically, even though certain innovations in the ecosystem do not require investment in broadband infrastructures, they significantly shape the nature of competition, the regulatory environment and also the investment incentives of broadband providers. As such, the complementary innovations can critically influence the path dependencies described above. Considering the evolution within the wider ecosystem requires recognition that the specific limitations and 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 innovations that modify network topology and help to localize traffic, intelligently balance network loads and mitigate the negative effects of suboptimal network infrastructure deployments (e.g., Stocker et al., 2017; Ai et al., 2018; Linthicum, n.d.). While Internet-based traffic flows thus become increasingly local, endpoint-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.[12] 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 imposed on network operators.[13]

Advances in the online distribution of content on the basis of complementary innovations will likely encourage broadband adoption and increase bandwidth consumption. Similarly, 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 dependencies) that may, for instance, prioritise the use of existing infrastructure over new

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

[13] 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; Claffy et al., 2018).

investment or diversifying (i.e., vertically integrating) into content and applications to develop and exploit additional sources of revenues.[14]

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 the demands for broadband capacities increase.[15] 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.

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.

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[14] 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.

[15] 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).

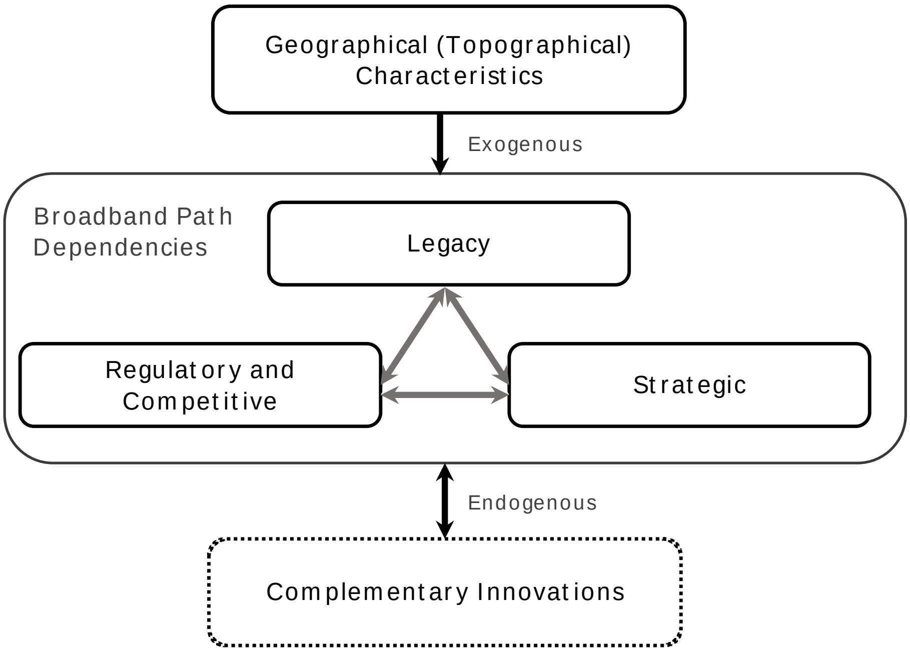

Figure 6: Network evolution and the path dependency triangle

Source: Own presentation based on Florence School of Regulation (2017, pp. 26-31)

4.2 Technological neutrality, market uncertainties 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). Pursuing the goal of "*incentivizing investment in high-speed broadband networks"* (CODE, recital 3), however, should not lead to the distortion of market outcomes through favouring certain NGA technologies ('winner-picking'). Deviating from the principle of technological neutrality would instead require sound empirical evidence on the welfare effects related to the available NGA technologies.

Bertschek et al. (2016) provide a recent review of the economic impact of broadband infrastructure and broadband 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 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).

There are only a few empirical studies that explicitly include NGA-based broadband data. One of those studies is by Fabling and Grimes (2016). Focusing on fibre deployment in New Zealand, they use firm-level data for the years 2010 and 2012. The authors estimate both the productivity gains as well as the effects on employment that can be attained from NGA broadband adoption. Interestingly, they do neither find a significant (average) effect of NGA broadband adoption on employment nor on productivity (Fabling and Grimes, 2016, p. 4). In another study, Bai (2017) conducts an empirical study on the relationship between broadband (downstream data) rates and their impact on employment rates. More specifically, the author distinguishes between three broadband speed tiers (basic, fast, superfast) and assesses whether these have a differential impact on employment. In doing so, the author uses US county level data for the years from 2011 to 2014. Even though a positive impact of basic broadband availability on employment can be identified, the study concludes that higher speed tiers did not generate substantially greater positive effects on employment. Only in case of complementary investment in organization capital, higher speed tiers lead to incremental and substantial employment effects. Finally, Briglauer and Gugler (2018) employ EU27 panel data for the period 2003 to 2015. The authors identified, similar to Bai (2017), a significant but rather small effect of NGA broadband adoption over and above the effects of basic broadband on GDP.

Hence, to date, empirical evidence as regards the differential impact of various NGA broadband technologies is sparse. The existing evidence indicates that the incremental benefits of NGA broadband might be overestimated and funding for ubiquitous coverage with high-cost FTTH/B networks would likely lead to net societal losses. This implies that when accounting for the currently low NGA take-up rates, existing and future second-life copper/coax technologies give rise to substantial cost advantages and therefore play a crucial role in shaping an efficient and market-driven migration process. That being said, the pace at which this migration process will forge ahead will depend on, among other factors, country specific characteristics (w.r.t. the availability and quality of 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, in particular, technological progress of future broadband access technologies (Briglauer and Cambini, 2017). 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 public authority is better informed about scalability in view of enormous heterogeneity in local access network topologies. This is reinforced in view of imperfect information available on future demand for high-bandwidth.

The CODE sets out three distinct coverage objectives (Section 0) to incentivize investment in high-speed broadband infrastructure. In doing so, "*very high capacity networks*" are defined 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 we explained above, the goal of enhancing the deployment of very high capacity networks should not be equated to favouring a specific broadband access technology. Rather, a preference for a specific broadband access technology requires economically sound evidence clearly indicating its comparative economic advantages. Even though the CODE does not explicitly single-out and push a specific NGA technology, it is suggested that FTTH/B connections might be considered as being preferred to achieve the deployment targets (e.g., recital 13 and Art. 2 (2)). However, at this point in time, deviations from the principles of technological neutrality in order to achieve the postulated connectivity targets as described in Art. 3 (3) lit c cannot be supported by sufficiently convincing empirical evidence.[16] Additionally, as shown in Section 3, the adoption and coverage of NGA broadband technologies

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[16] This has been summarized similarly in Florence School of Regulation (2016, p. 4).

exhibit substantial heterogeneities; this becomes obvious when comparing the numbers among western, eastern and northern European Member States. This heterogeneity in many respects presents a limitation to the goals of policy and target harmonization that constitute central elements of the CODE and aim to "*deliver conditions for a true single market by tackling regulatory fragmentation … and consistent application of the rules*" (recital 3).[17] While it is of course reasonable to apply the same rules to the same conditions, harmonization goals must not become a goal in and of itself—neglecting to account for the heterogeneous (empirical) market conditions and path dependencies within as well as between individual Member States. 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 (Briglauer and Cambini, 2017).

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.

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. Public funding 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

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[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.

unlimited bandwidth levels. 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.[18] 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; Vogelsang, 2013), common to all such regulations is that the 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. 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

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[18] 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).

performance targets or technology choices are, from an economic perspective, ad hoc outcomes of political institutions 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). Indeed, ‘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.[19] Broadband policies may aim to resolve such coordination problems on the basis of proactive and ambitious broadband targets 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 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

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[19] For a more generic discussion of relevant coordination problems in the context of complementary innovations, see Bauer and Knieps (2018, pp. 174-175). See also the insightful discussion provided in Middleton (2003) who argues that the value of broadband must not be narrowly attributed to, or derived from, the existence of a “single killer application”.

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. In this respect, Briglauer et al. (2016) describe that it seems rather unlikely that a public authority is better informed about the technological upgradability and economic scalability of specific access technologies than the broadband providers building and operating these infrastructures. 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).

Furthermore, 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.[20]

Lastly, cost synergies between fixed and 5G become increasingly important in the context of fixed-wireless convergence (Body of European Regulators for Electronic Communications,

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[20] 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.

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 provide guidance for policy decision-making regarding the role and economic desirability of technological neutrality. The flow chart figure is divided into several phases reflecting the different stages involved in the decision-making process. It begins with the initial target setting phase representing political outcomes at both the EU and national level.

In Phase I, broadband targets are set and introduced via public policies for high-speed broadband. Generally speaking, these typically focus on access technologies that are capable of meeting (expected) future demands (Section 2). Importantly, both the set of relevant dimensions of exogenously defined targets, as well as their specifications are determined within the political decision-making process outside the relevant markets and have a direct impact on the set of eligible access technologies. It is unsurprising that the specification of more challenging targets narrows the set of eligible access technologies. In this context, the targets may implicitly favour more fibre-based access technologies and thus – even though indirectly – to a certain extent also the scope of technological neutrality in Phase II.[21]

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[21] There are many dimensions that describe the stringency of broadband targets, for example, data rates (including symmetry of up- and downstream data rates; in the context of broadband policies, data rates are often referred to as ‘speed’), reliability, or jitter and latency. See, in this context, the discussion provided in Stocker and Whalley (2017, p. 24).

Given these targets and the de facto scope of technological neutrality, policy makers should – in line with the discussion in Section 4 – assess the relevance of externalities underlying eligible access technologies, the extent of path dependencies, upgradability and scalability of hybrid NGA networks and market uncertainties as well as of local (geographical) heterogeneities in Phase III. In this phase, policy makers should first assess the actual extent of externalities related to eligible and de facto favoured access technologies. This is important as policy interventions in terms of defining public policy targets presupposes substantial market failure in the first place. Policy makers should then assess the extent of the availability and technological state of existing infrastructures and both their upgradability and scalability. The reason why we have introduced this factor before assessing technological and demand uncertainties is that the former is easier to assess whereas the latter arguably presents a far more challenging task. Finally, if the previous factors indicate that abandoning technological neutrality is socially desirable, policy makers should then assess the extent of regional heterogeneity. As was shown in Section 3, costs may vary substantially across different regions. This might also be true for path dependencies as described in Section 4.2. Depending on the geographical heterogeneity, geographically differentiated roll-out scenarios (e.g., favouring FTTH/B deployment in low cost urban areas only) might be required.

In Phase IV, public policy recommendations as regards the desirability of technological neutrality can be derived. The final decision to 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. The absence of externalities, and hence absence of associated market failure, rather suggests letting quality parameters be endogenously determined by competitive market dynamics. Public funding is in this case restricted to address distributional concerns related to universal service obligations requiring basic connectivity for the poor and in high-cost areas.

It is worth noting that although the binary nature (Yes/No) of the individual decision points is simplistic, it points to the need for rational decision-making on the basis of sufficient empirical evidence on all factors to be assessed in Phase III.

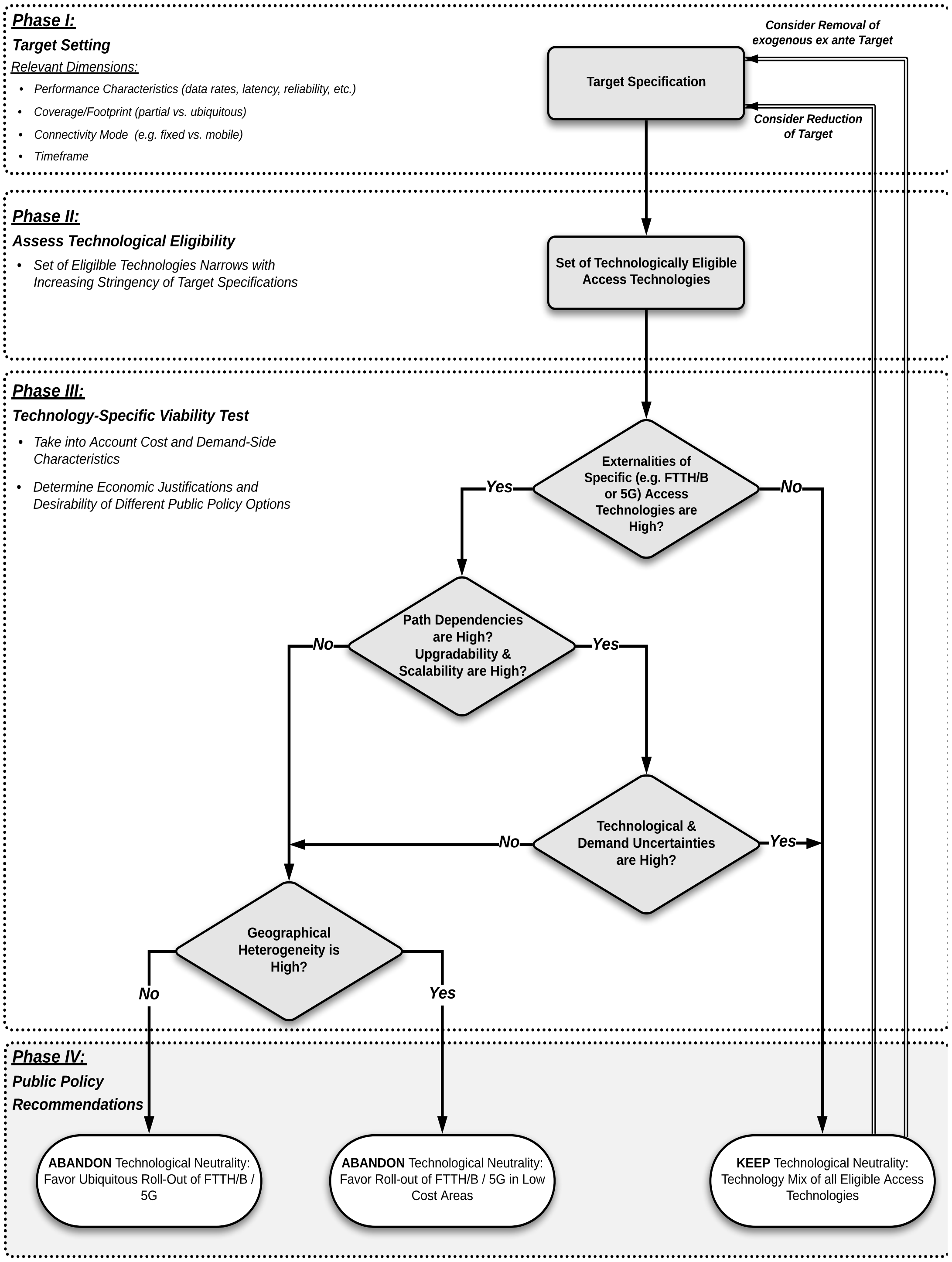

Figure 7: Technological neutrality policy-making process

Source: Authors’ own presentation

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.

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 harmonized 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) in view of disproportionally increasing costs to cover very remote areas.

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. Against this background, it seems rather unlikely that a ‘social planner’ (a role that is played by the policymakers when deciding on broadband targets) is better informed than (active) broadband providers, in particular, when considering the tremendous complexity and heterogeneity within and between Member States. Even more generally, public policy interventions that aim at picking specific technologies as ‘winners’ can only be economically justified from a welfare perspective, if market-driven network evolution demonstrably yields inferior and thus undesirable 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

- the extent of externalities related to deployment a specific NGA access technology;
- the extent of legacy-based path dependencies, upgradability 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 focus on gathering reliable empirical evidence on the relevance of each of these key factors.

If Members 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 FTTH/B) 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.

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