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The advent of 5G and the non-discrimination principle☆

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ABSTRACT

5G promises to be a game changer for the extended connectivity-based value chain, encompassing a much broader set of digitalized industries than previous solutions. By reshaping competition among market players and among technologies, it changes the trade-offs underlying the application of the non-discrimination principle. In this paper, we provide a unified view of the implications of these technological developments for four instantiations of this principle that span the entire digital value chain: non-discrimination in FRAND licensing of standard-essential patents (SEPs), vertical separation remedies, network neutrality and technological neutrality. We conclude that overly rigid and non-technology neutral interpretations of the non-discrimination requirement would be at odds with technological evolution and would be incompatible with the objective to maximize the overall value of digital networks.

1. Introduction

The non-discrimination principle plays a key role in electronic communications regulation. The EU regulatory framework contains a variety of rules disciplining access to essential infrastructures, such as price and non-price regulation of mandated access, rules on incumbents' vertical separation, and network neutrality rules. Behind them can be identified a view of networks as general-purpose inputs that enable investments in service differentiation and applications. From this perspective, the restrictions to contractual and organizational freedom introduced through the application of non-discrimination (henceforth, ND) requirements serve the purpose of maximizing the overall value of the system, including the common input and its applications (Wu, 2006).[1] Different ND rules enable free entry, ensure a level playing field for market players, independently of the degree of their vertical integration along different rungs of the value chain, and safeguard investment of firms willing to develop the network or provide new services on top of it. In addition, ND rules address market power issues deriving from the control of the network/common input, ensuring a level playing field for market players.

A similar logic may be used to interpret the ND requirements imposed upstream the digital value chain, to participants in the

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[1] This general insight has been explored from different angles. Wu (2004) has come to it from what he calls "innovation commons" theories. His view has been amply discussed in legal scholarship. Economists have referred to Internet service providers (ISPs) as two-sided platforms (see, e.g., Peitz and Valletti, 2015). More generally, network infrastructures are frequently referred to as platforms that give rise to valuable ecosystems (see, e.g., Gawer, 2009).

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development of standards for basic telecommunications technologies. In this case, the ND principle is applied as a contractual commitment of holders of standard-essential patents (SEPs) to license on *Fair, Reasonable, and Non-Discriminatory Terms (FRAND)* and as a prohibition of discriminatory practices under competition law. Limitations to SEPs owners' ability to license at their preferred terms are meant to safeguard implementers from opportunistic behaviours and distortions of competition, promoting investments in standard adoption and application.

In both cases, implementation of the principle may have different degrees of flexibility. ND can be considered compatible with various extents of differentiation of contractual terms. Rules can be crafted or interpreted in ways that are tied to specific technological and market environments or more technology-neutral. Getting the interpretation of the ND principle right is not straightforward. Since the different instantiations of the ND principle involve limiting to various extents the freedom to operate of large firms who control key resources, as well as more generally contractual freedom, they also entail trade-offs in terms of both static efficiency and dynamic efficiency. From a static standpoint, trade-offs emerge because ND rules may affect firms' ability to achieve economies of scale and scope, the extent of transaction costs they face, and the size and nature of the externalities that emerge in production. Most importantly, from a dynamic standpoint, ND rules need to balance the incentives to invest in the infrastructures and services of both incumbents and new entrants.

A different instantiation of the ND principle relevant to the digital value chain is given by the principle of technological neutrality. The latter applies to regulators and policymakers and is meant to prevent regulatory actions from distorting competition across different technologies. It preserves firms' freedom to make technological choices based on their private information and may therefore indirectly affect incentives to invest in networks. Technological neutrality is also subject to varying degrees of flexibility in interpretation and imposes its own trade-offs. Limiting firms' freedom to choose among different technologies may promote investment in technologies with significant external effects, but entails the obvious risk of picking the wrong technological solution.

In this paper, we discuss the foreseeable impact of 5G-induced technological change on the interpretation of these two instantiations of the ND principle, as applied to market players and policymakers. We jointly consider the changes brought about by 5G upstream and downstream the value chain – something we believe is still lacking in the emerging (highly speculative) literature on the implications of 5G for regulation (e.g. Alexiadis & Shortall, 2016; Bauer and Bohlin, 2018; Cave, 2018; Frias & Martínez, 2017; Yoo and Lambert, 2019). We abstract from many nuances and possible alternative interpretations of the rationale for the ND principle and focus on its role in balancing incentives to invest in common inputs (networks and essential patents) and their applications – a view that has become progressively more central to the policy debate on different ND issues as technological change has pushed to the forefront the need to build new (fixed and mobile) networks. This allows highlighting some common themes relevant across the entire digital value chain, along with more specific policy implications for the different implementations of the ND principle considered.

While there is still considerable market and technological uncertainty surrounding 5G, one implication of this technology seems rather uncontroversial: it promises to be a game-changer of competition and value creation along the Internet Protocol-based (IP-based) value chain. 5G is not only expected to bring about sizable performance improvements along many dimensions of standard service provision, but it also turns networks from general-purpose connectivity platforms to flexible and scalable collections of resources that can be combined and reconfigured in multiple ways. It enables a much greater extent of resource sharing both horizontally – among players at the same level of the value chain – and vertically – among network operators and content and applications providers/verticals (e.g., automotive, health, smart domotics, etc.). This has important implications for the ND principle.

First, 5G is set to multiply the opportunities for cooperation across different layers of the value chain (Mumtaz et al., 2017; Yrjölä et al., 2018). Market-based, contractual forms of interaction will span previously disparate industries, brought together under extended digital value chains organized around specialized verticals. The sheer number of contractual interactions is going to increase, making the ND principle more salient and raising novel issues in its interpretation.

Second, 5G will give rise to new forms of complementarity and substitutability among technologies and services, changing the nature and accessibility of the resources that are key to competition and therefore, to some extent, the meaning of the scarcity issues underlying the application of the ND principle. It will reshape the competition among market players and technologies, influencing the market structure and market power, while opening up novel opportunities for investment in infrastructures and services. This is bound to change the meaning and the complexity of ND problems. Most importantly, the increased scope for value creation through novel contractual relationships raises the opportunity cost of limiting firms' contractual and organizational freedom through overly rigid interpretations of the ND obligation. Indeed, the substantially greater possibility of vertical and horizontal differentiation of product offerings opens up much wider opportunities for efficiency-enhancing forms of contractual differentiation, to accommodate the needs of different 'verticals', i.e. digitized downstream industries.

Finally, 5G is associated with a substantially increased degree of uncertainty. There is some discussion as to whether 5G is a General Purpose Technology, which would entail that the scale and scope of the changes connected to it would be of a particularly significant magnitude, but even if the definition didn't fully apply, there is no doubt that uncertainty in the evolution of technologies and markets will loom large. One could say that 5G, by enabling a wide range of innovations, brings radical uncertainty in the sense proposed by Frank Knight (1921) - uncertainty that is extreme and non-measurable because the very distribution of probabilities across different possible future events is unknown, not only the likelihood that a specific event will materialize. This further raises the opportunity cost of constraining firms' contractual freedom.

Two main general implications for the interpretation of the ND principle emerge from the analysis. On one side, it appears that 5G-induced technological change makes obsolete technology-dependent and market-structure-dependent interpretations of the principle. This holds for industry-specific interpretations of the ND prong of the FRAND licensing requirements such as the criterion of the so-called Smallest Saleable Patent Practicing Unit (SSPPU) as well as for the notion of "specialized services" in the context of network neutrality rules. On the other side, the increase in the opportunity cost of limitations to contractual and organizational freedom induced by 5G suggests that such limitations should be minimized. Flexible contractual solutions are indispensable to accommodate uncertain future combinations of resources and promote investments. Applications of the ND principle that force uniformity, including uniformity of SEPs royalties, forced adoption of a vertically-separated organizational form, and the zero-price aspect of network neutrality rules (which obstacles QoS differentiation) should be avoided.

The paper is organized as follows. Section 2 reviews the key technological building blocks underlying 5G, the improvements it is expected to generate in terms of performance of existing services, the scope it opens up for entirely new applications and novel flexible combinations of resources along different 'verticals', and the main impacts of these developments for the extended 5G-enabled value chain. In sections 3 to 5, we consider in turn the implications of the technological and market changes brought about by 5G for the different instantiations of the ND principle that we examine in this paper: the non-discrimination prong of the FRAND requirement in SEP licensing, rules on vertical separation, network neutrality and technological neutrality.[2] Section 6 concludes.

2. Key technological developments brought about by 5G

5G literally refers to the fifth generation of mobile technologies, as defined by the set of telecommunications Standard Development Organizations united within the so-called 3rd Generation Partnership Project (3GPP). While the acronym seems to indicate a simple evolution with respect to previous generations of mobile connectivity, there are many reasons to believe that 5G may evolve along a revolutionary path (Lemstra, 2018), acting as an enabler of a range of innovative applications (Teece, 2019) or even assuming fully the nature of a new General Purpose Technology (GPT) if considered broadly in the context of the overall connectivity system (Knieps & Bauer, 2021).

5G promises to be much more than an incremental improvement over 4G LTE in at least three respects: speed performance, projected to be about 600 times better than the current 4G LTE standard; network latency, enabling instantaneous and real-time communication across devices and applications; and capacity, leading to ubiquitous connectivity with an astonishing 100× increase in traffic capacity and network efficiency and thus substantially overcoming traditional considerations about band scarcity that marred previous generations of mobile connectivity (Qualcomm, 2019). More importantly, the extremely high speed, ultra-low latency, and massive capacity brought about by 5G will enable a wide range of new applications, from virtual reality (VR) and augmented reality (AR), to full industrial automation with real-time data synchronization, fully autonomous vehicles, and robotic surgery – all cutting-edge technologies and applications that require high-speed data transfers and high responsiveness.

The following three subsections elaborate further on the 5G promise of ubiquitous connectivity by illustrating the key technological building blocks and architectural features underpinning the above-described performance improvements (section 2.1), by detailing the main applications and use cases as currently envisioned by 3GPP, and by sketching the main novelties expected from this evolution toward an extended connectivity value chain (section 2.2).

2.1. 5G main architectural and technological features

5G networks abandon the "one-size-fits-all" logic of traditional connectivity in many respects. They utilize a broader set of spectrum resources that combines low-band and high-band wireless spectrum, by relying on both the traditional tower and antennas infrastructures and on a high number of dispersed antennas corresponding to smaller cells, for which the problems with longer-range propagation using higher-frequencies do not tend to arise. *Densification* of the access network, with the addition of extremely high-frequency millimeter-wave (mmWave) small cells is one of the key technological developments underpinning the increase in network capacity and the corresponding decrease/disappearance in the scope of network congestion expected from 5G (Bhushan et al., 2014). Together with the architectural changes described below, it is also at the origin of the increased flexibility and scalability of the deployment of network resources that will enable a range of new applications.

Most importantly, 5G abandons the "one-size-fits-all" logic through a remarkable shift in network architecture that combines the decomposition of network functions in separable units that can be virtually recombined with great flexibility, weakening or overcoming the link with the underlying physical resources, and leading to a "softwarization" of the network, based on the management and orchestration of the different functions. 5G networks' underlying hierarchical structure and architecture are closer to the resource sharing logic of the Internet, especially in its most recent phase dominated by cloud computing, than to the management of rigid physical infrastructures that has so far characterized wireless networks. 5G thus enables unprecedented levels of resource sharing at different levels of the wireless communication infrastructure, from spectrum use to service provision.

The two key technologies at the heart of the shift towards greater resource sharing and the associated increased flexibility in the management of resources and the provision of a wide variety of services are *Network Function Virtualization* (NFV) and *Software Defined Networks* (SDN), which jointly enable a conceptual evolution of the network called *network slicing* (see, e.g., GSMA, 2017; Afolabi et al., 2018). Network slices can be defined as "*end-to-end (E2E) logical networks running on a common underlying (physical or virtual) network, mutually isolated, with independent control and management, and which can be created on demand*" (Ordonez-Lucena et al., 2017). This definition highlights several key aspects. First, slicing allows for the coexistence of multiple separated virtual networks to run over the same physical network in order to provide a variety of services and cater to different use cases. Each virtual network can be managed to respect different levels of service (SLA) and to provide different functionalities. Second, the control of the various functions performed

[2] A selection is needed for space constraints. However, we acknowledge that these are by no means the only ND issues relevant in connection with 5G. For instance, data neutrality issues deserve the utmost attention (see, e.g., Easley et al., 2018).

by each separate network can be delocalized, i.e. exercised independently by tenants/users without centralization in the hands of the network provider. Finally, network resources can be combined on-demand and in real time, to offer services on the fly.

An additional key technological development that is complementary to 5G connectivity and is currently part of 3GPP's discussions around Release 17 of the standard is Edge Computing. The latter refers to the further shift of the intelligence of networks from the core to the edges, something that enables services to be hosted closer to consumers, thus allowing for efficiency gains in terms of reduced end-to-end latency and decreased load on the transport network. The implementation of Edge Computing solutions depends on the ability to implement large-scale and pervasive Wide Area Networks spanning large geographical areas. Once these will be in place, the shift of processing power towards customers will enable applications to be run on devices smaller and less capable than current PCs without loss of performance. This, in turn, will crucially contribute to the viability of many 5G applications and use cases (IoT applications, virtual and augmented reality, real-time gaming, see below, section 2.2). Moreover, similarly to network slicing, it will foresee an increase in the number and complexity of the relationships involved in the provision of connectivity services by requiring the collaboration of multiple providers: infrastructures will be put in place by Edge Computing Service Providers (ECSP) and used by the Mobile Network Operators (MNO), while an extended range of applications will be provided by Application Service Providers (ASP) connected through Application Programming Interfaces (APIs).

Overall, softwarization, virtualization, and Edge Computing will enable more effective optimization in the use of resources, something that, together with network densification, further contributes to the massive increase in available capacity. What is economically relevant is the fact that this 5G architecture will be able to support the provision of services on a range of very different digitized value chains in a plurality of industries such as automotive, manufacturing, healthcare, and media. These industries are likely to be significantly transformed by 5G, which enables novel and endless combinations of resources, business models and interactions among different stakeholders. It is to these novel applications, and the associated changes to the value chain, that we now turn.

2.2. 5G applications and impact on the extended connectivity value chain

Among the many applications of 5G, the most telco-centric and traditional is given by *Enhanced Mobile Broadband*, which envisions performance improvements over existing connectivity and end-user services (outdoor wireless broadband, ultra-high-definition broadcast, mobile streaming, 3D multi-player gaming, and virtual meetings) as well as completely new applications based on virtual reality and augmented reality (virtual dressing rooms; fully immersive entertainment experiences; and remotely provided healthcare services). These are already close to large-scale commercial implementation, partly because they have mostly an evolutionary nature with respect to previous generations of mobile connectivity, and do not entail, *per se*, profound changes to the value chain.

The applications that are most susceptible to altering the traditional connectivity value chain are those associated with *Massive Machine Type Communications* (mMTC) and *Ultra-Reliable and Low Latency Communications* (URLLC).[3] The first, defined also as Massive Internet of Things (MIoT), leverages the possibility, enabled by 5G, to efficiently transmit small amounts of data from billions of devices, satisfying demanding requirements in terms of connection density, uniform coverage, low energy consumption, and low latency. This, in turn, generates endless applications in both the consumer and the industrial world, such as smart homes, enhanced purchasing experiences through proximity marketing, wearables for e-health applications, smart cities, smart agriculture, smart metering in the utility sector, and remote industrial monitoring. Finally, the heading *Ultra-Reliable and Low Latency Communications* identifies the class of so-called Mission Critical Services that 5G enables by virtue of the enhanced performance in terms of speed and reliability that promises to allow preventing the disastrous consequences of occasional failures to ensure instantaneous data transmission. Autonomous vehicles as well as some advanced e-health applications fall within this category.

Any of these applications corresponds to possible new IoT "verticals", based on the provision of network resources in the form of flexible and programmable services, accessible within relatively short time horizons, on top of a shared common infrastructure. "Verticals" magnify the possibility to create new business models and forms of cooperation between connectivity providers and players in traditional product and service industries. Indeed, the increased scope for resource sharing allowed for by 5G will bring about unprecedented levels of cooperation across different layers of the value chain (Mumtaz et al., 2017). More generally, market-based interactions become relatively easier to adopt as a form of organization of economic activity in presence of 5G enablers cloud, virtualization, and service integration (Yrjölä et al., 2018).

The breadth and scale of this phenomenon can be gauged already at the level of standard-setting. One first notable aspect that predates 5G is the progressive trend away from vertical integration and towards the emergence of specialized technology suppliers in the context of an open innovation model (Teece, 2019). 5G has magnified this trend. While some extent of ex-ante coordination necessarily characterizes standards in general – and has characterized the previous successive generations of mobile connectivity – 5G is unique with regard to the number and nature of players necessarily involved in the standardization effort. Market players from any geographical location and a range of very different and previously separated industries are involved in the unified effort at developing 5G under the coordination of a single body (3GPP).

Also, as a natural consequence of ex-ante coordination in standard development, significantly increased cooperation is expected to come from market implementations of the 5G standard. Network slicing and network densification, by enabling the provision of network resources in a modular, scalable and elastic fashion, through recombination of subsets of resources into a range of IoT

[3] This typology of classes of services has been defined by 3GPP in Release 15 of the 5G standard. Additional classes of service have been (and will be) defined in subsequent Releases, such as for instance Vehicle-to-Everything (V2X), satellite access and wireline convergence.

"verticals", open up the way to new business models and forms of cooperation between connectivity providers and players in the increasingly digitized product and service industries. The concept of multi-tenancy thus goes much beyond the current set of relatively standardized interactions among telco players. As connectivity moves towards an "as-a-service" model and away from the notion that applications with specific requirements entail the acquisition of dedicated networks, relationships between different players along verticals become more granular and flexible. Network services have to be provided on-demand, often in real-time, and with a wide range of requirements in terms of speed, capacity, and latency, to both Over the Top and downstream vertical industries.

The key novelties relate to the inclusion of new players and the emergence of new roles in the fully converged connectivity/IT value chain (Elayoubi et al., 2017). Business-to-business interactions will significantly increase, along with the increase in human-to-machine and particularly machine-to-machine interactions. Players from industries as diverse as automobiles, energy, and healthcare may perform the role of Online Service Providers (OSPs) by relying on the resources available *as a service* from Communications Service Providers (CSPs) that, in turn, may be independent of Network Service Providers (NSPs). New software and service providers from the IT world may offer an expanded range of services in the converged telecom, computing, and storage value chain. In this context, it is natural that NSPs will find it efficient to increasingly share resources (including infrastructures and spectrum) among themselves. Overall, value creation will occur through the involvement of a broad range of players and a dense web of contracts and partnerships among them.

Fig. 1, based on Elayoubi et al. (2017), presents a simplified 5G connectivity value chain, which highlights the variety of market players involved and the key contractual relationships enabling value creation. For simplicity, the figure does not contain one additional category of market players that is likely to become progressively more important in smoothing the extended web of transactions the figure illustrates – brokers – who are expected to facilitate relationships particularly among NSPs and between NSPs and OSPs. However, it does include one category of upstream market players – technology providers – that is not separately considered in Elayoubi et al. (2017) and, more generally, in discussions of the 5G value chain, but provides the foundation for all the technological implementations occurring downstream.

3. Non-discrimination in the licensing of standard-essential patents (SEPs)

The first set of ND rules that we consider applies to technology providers in the context of the licensing to implementers of the patents that they contribute to standard-setting efforts and are considered essential to the standard. Standard Development Organizations (SDOs) normally require the owners of standard-essential patents (SEPs) to commit to license according to "*Fair, Reasonable and Non-Discriminatory*" (FRAND) terms. ND is therefore an essential contractual requirement to participate in standardization. In addition to this contractual prohibition of non-discrimination, SEP licensing is also subject to the prohibition of non-discrimination that arises under competition law. In Europe, this is contained in art. 102, which forbids discrimination that "*result[s] in an actual or potential distortion of competition*" and that lacks "*objective justification*."

The non-discrimination prong of the FRAND formula, together with the other requirements of SEPs licensing, is meant to ensure that standard developers receive a fair return on their investment while assuring implementers that any specific investment in the application of the standard will not be jeopardized by opportunistic attempts to extract unreasonable royalties from the licensing of SEPs.[4] The limitation to the contractual freedom of SEP holders is thus intended as a means to the end of maximizing the overall value of the standard, including the standard itself and its applications. Antitrust-based ND rules additionally seek to ensure that implementers in the same relevant market can compete on an equal footing, without facing distortions and barriers to entry due to technology providers' licensing practices – something that has implications for both static and dynamic efficiency.

While this high-level characterization of the ND requirement in SEP licensing can be considered relatively uncontroversial, its concrete implications for the design of the non-discrimination principle are much less univocal. There is no consensus either on the judicial application of the principle or on its theoretical legal and economic analysis. Sidak (2017) reviews a wide range of both positive and normative interpretations, grouping them under three categories: (a) ND as a duty to license (see, e.g., Mariniello, 2011); (b) ND as a prohibition against price discrimination between downstream competitors (see, e.g., Swanson and Baumol, 2005) and (c) ND as a duty to license similarly situated licensees on similar terms (see, e.g., Carlton and Shampine, 2013). This distinction, and the wide variance of interpretations existing within each category, highlight the difficulty of turning the non-discrimination concept into an actionable set of prescriptions/prohibitions that may give guidance to both technology providers and implementers. Indeed, each of these interpretations can entail more or less stringent and rigidly defined constraints on SEP holders' contractual freedom. The distinction also clarifies that the two provisions against discrimination in SEP licensing – contract-based and competition law-based – overlap to some extent but are not necessarily to be considered perfectly aligned.

The advent of 5G is bound to make the application of the ND principle in SEP licensing ever more relevant and complex for two main reasons. The first is that the range of ND issues arising in the 5G context is going to be broader, as 5G technologies and standards are going to be incorporated into a much broader set of products than it used to be the case with previous connectivity standards. The second is that the radical uncertainty brought about by 5G makes it more difficult to find the appropriate balance of incentives between SEP holders and implementers. In what follows, we will elaborate on these two points in turn, to capture the essence of the ND issues at hand, rather than the details of the many legal and economic conundrums specific to this domain.

5G standards are an input into products that differ widely in terms of cost, value created, price and functionality. The underlying

[4] This economic interpretation is explicit in US jurisprudence. For instance, it features prominently in the set of principles the court developed for the determination of FRAND royalties in the Microsoft vs. Motorola (2013) case (Heiden, 2016).

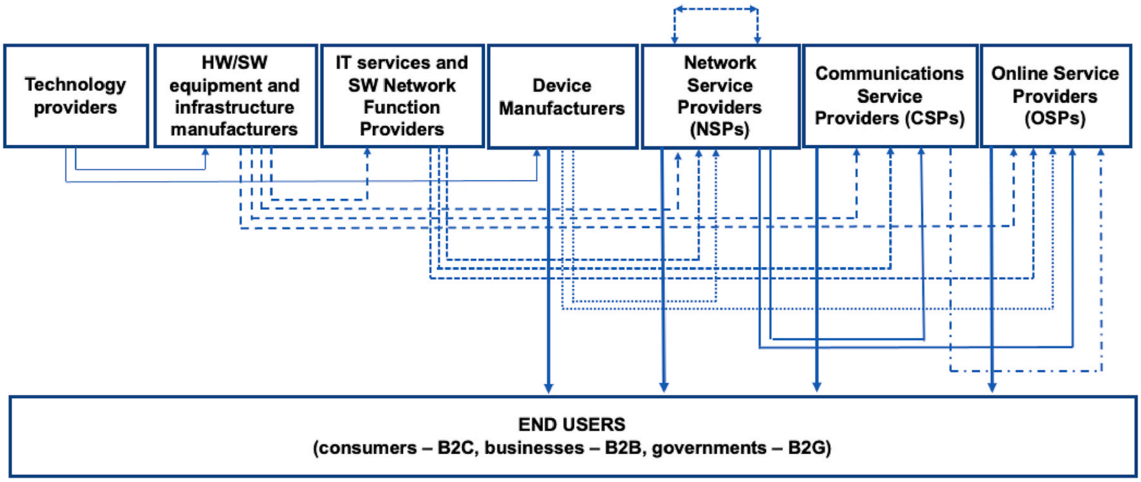

Fig. 1. The 5G extended connectivity value chain
Source: author's elaboration on Elayoubi et al., 2017.

value chains in the various sectors involved may be very different, as well as the nature of the prevailing licensing practices. To make just one example, while in the traditional mobile communication value chain licensing normally involves manufacturers of end-user devices and manufacturers of network equipment, in the automotive industry standard licensing has traditionally occurred upstream the value chain, at the level of component suppliers. The nature of licensing revenues is also set to change. Rather than deriving from a relatively homogeneous group of firms such as smartphone or equipment manufacturers, licensing revenues will likely come from a broader set of licensees and have a low unit value, while still adding up to a comparable or possibly higher amount. Most importantly, these changes bring about also different practices in the methods of patent valuation and in the definition of other aspects of licensing.

The implications are numerous, but one stands out: the nature of the relevant ND issues that need to be addressed will be different than it used to be the case when connectivity was the preserve of the (mobile) communication value chain. A similar clash of licensing cultures has already emerged in the smartphone value chain (Heiden, 2016), but the underlying ND issues concerned homogeneous goods. The key issue to evaluate the presence of unjustified differential treatment has been the assessment of whether producers heterogeneous in terms of size, market success, or geographical location were "similarly situated". As 5G is incorporated in a range of different sectors, an additional relevant issue will emerge, i.e. how the ND principle should be applied to firms that use the same standard to market products that are heterogeneous in terms of the value that they derive from the incorporation of the standard. For instance, the incorporation of 5G connectivity in autonomous cars generates an incremental value that is not comparable to the incremental value generated by incorporation of 5G functionalities in a smart-metering device or a smart-home appliance, both of which may use connectivity much more sparingly than an autonomous vehicle that requires real-time data synchronization to fulfil its function. How this issue should be addressed is not obvious.

This new ND issue lies behind two of the main debates that have engaged practitioners and policymakers discussing the future of 5G standards in the past few years: use-based licensing and the appropriate level of the value chain at which licensing should occur. Use-based licensing refers to the idea that royalties should be linked to the intensity of use of the standard by different end-user products. According to this logic, charging higher royalties to the autonomous car producers in the above example than to producers of smart home appliances should be considered non-discriminatory. The choice of the licensing level is also cast in terms of non-discrimination, although in this case apparently not as a matter of royalty level, but as a duty to "license to all" the levels of the value chain. Proponents of the "license to all" principle hold that non-discrimination entails that SEP holders should make available FRAND licenses to all component manufacturers along the value chain, not only to manufacturers of end-user devices.[5]

It is important to note that behind both debates there is the issue of whether non-discrimination entails uniformity of the royalties across different implementations of the standard and, by implication, the lowest common royalty across the different products. Indeed, if a single price has to be defined for SEPs used in widely heterogeneous applications, it must necessarily be the lowest price across the different applications. To choose otherwise would make low-value products incorporating SEPs (such as for instance, IoT sensors) uneconomical.

This interpretation of the issue is straightforward for use-based licensing but applies equally to the choice of where in the chain to license because of the joint effect of the doctrine of patent exhaustion and of a criterion called the "Smallest Saleable Patent Pricing Unit" (SSPPU). Patent exhaustion refers to the notion that patentees relinquish all control over their IP once they sell or license it, so that they cannot invoke patent law to limit in any way the use buyers make of the patent. This includes the possibility of selling

[5] The two main advocacy groups on the opposite sides of the debate are IP Europe, which includes Airbus, Ericsson, Nokia, Qualcomm and Fraunhofer, and the Fair Standards Alliance, championed by Apple, Intel, Google and Cisco along with many of the European automotive manufacturers.

products that incorporate the IP, both final products and intermediate inputs. The SSPPU is a royalty valuation method used by courts and SDOs that is based on the identification of the value added by the patent to the smallest component that implements the patent and that is sold on the market. It has been developed in US jurisprudence, but generalizations of its application as a pricing rule have been proposed or adopted in many contexts, from SDOs' IP guidelines to antitrust cases (Layne-Farrar et al., 2014). These criteria, together with the notion of non-discrimination as a duty to "license to all", jointly entail uniform royalties set at a level compatible with licensing to producers of low-value components. Indeed, once a chip manufacturer obtains a SEP license, she can sell downstream to a car producer the chip embodying the patent functionality free and clear of all patent rights, so that royalties are driven down to the lowest level in the value chain.

ND issues are expected to reach a new level of complexity also because of the uncertainty that 5G is likely to bring about. Uncertainty makes it even more difficult to design the ND requirement in a way that adequately balances the incentives of technology providers and implementers. Indeed, in the SEPs context, uncertainty gives rise to two opposite effects. On one side, it increases the benefits from adopting rigid ND rules, which provide a strong contractual safeguard to implementers. This is because contractual safeguards matter more for incentives to invest in applications of the standard when returns on investment are subject to greater uncertainty. On the other side, it also increases the cost, in terms of incentives to invest in the standard, of significantly constraining SEP holders' contractual freedom through rigid interpretations of non-discrimination. This cost is magnified by the fact that technological uncertainty amounts to a broad set of opportunities to invest in the standard in order to adapt it to different potential applications. An overly rigid application of non-discrimination rules may thus exert a negative effect on the overall value of the standard, through the reduction in the incentives to invest in the standard that serves as a common input to many applications, of a much greater magnitude than in other SEPs contexts.

No clear policy answer to these questions has emerged yet. In May 2017, the European Commission set out to clarify issues related to SEP valuation, making explicit, among others, the objective to "*provide a level playing field to businesses preparing 5G and those using connectivity applications*"[6]. The ensuing November 2017 Communication adopted a light-touch approach and left unaddressed the two core issues of usage-based licensing and appropriate level of licensing in the value chain[7]. The January 2021 Report by the SEPs Expert Group subsequently appointed by the Commission to clarify a range of SEPs licensing issues also concluded, with regard to non-discrimination, that "[i]*t is important to maintain some level of flexibility in the interpretation of the ND commitment so that licensors can accommodate the licensees' specific needs and situation; and yet, it is uncertain how much flexibility licensors may have in offering different terms and conditions while staying within the bounds of the non-discrimination obligation. There exists no clear guidance on this issue in legal doctrine or jurisprudence*." (Baron et al., 2021, pp. 115–116).

The need for flexibility invoked by the Expert Group should be taken seriously (even more seriously than it appears to be the case in the Report). Some declinations of the principle are particularly inflexible and cast in very technology-dependent, or non-technology-neutral, terms. This is particularly the case for a rule such as the SSPPU, which is aligned to the reality of sectors where component-level licensing is prevalent. Most importantly, explicit or implicit drifts towards uniformity of prices should be avoided because they are likely at odds with the objective of maximizing the overall value of the standard, including development and adoption/implementation. Indeed, the basic economics of cumulative innovation (see, e.g., Scotchmer, 2004) supports the idea that, to balance incentives, part of the value of any specific application should be appropriated by the developer of the upstream input through efficient contracting, because part of the social value of the input resides in the applications that it enables. Thus, royalty differentiation *per se* appears *prima facie* efficient also in this specific context. The concern that royalty differentiation would allow SEP holders to appropriate part of the value created through the investment made by implementers through opportunistic behaviour – the main argument against usage-based licensing – may be addressed through close and fact-specific antitrust scrutiny and institutional innovations (on which more below) rather than by ruling out royalty differentiation altogether.

The difficulty in applying the cumulative innovation logic to 5G-related SEPs possibly resides in the fact that in some sectors/value chains it is more straightforward than in others to look at connectivity standards as essential inputs according to that logic. Stated differently, SEPs may have different degrees of "essentiality" in different sectors. 5G appears certainly more of an essential input in advanced e-health applications than in a connected vending machine, so that it is harder to interpret the latter case through the basic innovation/application logic. However, this does not undermine the basic economic intuition that contractual freedom is key to the efficient division of rents in a cumulative innovation context. It reinforces the rationale for avoiding uniform royalties. Moreover, the application of the cumulative innovation logic to 5G standards is also complicated by the concern for royalty stacking, i.e. for the possibility of an exceedingly high cumulative set of royalties charged by producers of different components along the different "verticals". The relevance of this concern is, however, scaled back by estimates of the overall royalty burden at less than 4% in the mobile phone value chain (Galetovic et al., 2018).

Second, interpretations of the ND obligation that entail uniformity of royalties would have the effect of generating, loosely speaking, a form of "reverse discrimination" among SEP owners. Holders of SEPs that happen to hinge on components with a relatively higher value will obtain a higher remuneration than other SEP holders. This is not only a distributive problem but also a problem in terms of incentives to invest in development of the standard. Anchoring SEPs remuneration to the value of the smallest component on which the patent hinges, as per the SSPPU pricing criterion, does not allow to align the value that can be appropriated to the value that

[6] European Commission (2017). Standard Essential Patents for a European Digitalised Economy, available at https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2017-1906931_en.

[7] Communication from the Commission to the European Parliament, the Council and the European Economic and Social Committee Setting Out the EU Approach to Standard Essential Patents, COM/2017/0712 Final.

patents effectively create and therefore distorts incentives.

Of course, as mentioned above, the downside of flexibility (i.e., of renouncing to adopt overly rigid interpretations of ND) is the possibility of greater uncertainty faced by implementers. However, there are ways to address this problem different from renouncing to flexibility altogether. One possibility is to devise novel forms of organization of SEPs licensing. The EC-appointed Expert Group has proposed a number of possibilities that revolve around the idea of creating patent pools already during the final phase of standardisation, so as to mitigate the potential for hold up and hold out issues and to coordinate licensing in order to ensure a reasonable aggregate level of royalties. Ex ante contracting within SDOs or patent pools could also be complemented by the adoption of an adaptive ("Bayesian") method for updating royalties as more information becomes available to reduce uncertainty (something we have proposed in a related article – Parcu et al., 2021). While discussing these organizational solutions is outside the scope of the present paper, their availability suggests that the ND requirement can be applied without imposing unnecessary restrictions to contractual freedom.

4. Network-level non-discrimination rules

The most fully articulated and specific ND rules relevant to the 5G value chain are those imposed on network operators. The first set of rules of this sort concerns specifically firms that control essential facilities and are therefore designated as having Significant Market Power (SMP) in fixed connectivity and is meant to preserve a level playing field between the vertically integrated incumbent and competitors relying on access to the incumbent's network. The second, more recent, category of rules is given by network neutrality rules, which apply to all telecommunications operators, both wireline and wireless, and discipline discriminatory behaviours towards consumers and service providers. In what follows, we will consider the impact of 5G on both sets of rules in turn, having specific regard for their implications for incentives to invest and to innovate in networks and services.

4.1. Non-discrimination in access and interconnection

The general notion of non-discrimination in access and interconnection is defined in Article 10 of the European Access Directive. It applies to operators with significant market power (SMP) and requires that *"the operator applies equivalent conditions in equivalent circumstances to other undertakings providing equivalent services, and provides services and information to others under the same conditions and of the same quality as it provides for its own services, or those of its subsidiaries or partners."*[8]. A similar notion of non-discrimination may apply in specific circumstances also to non-SMP operators, such as for instance in the context of the application of symmetric access obligations. The same 2002 Directive also contains a provision granting regulators the ability to impose full structural separation to radically address incumbents' incentives to exercise forms of price and non-price discrimination (art. 8(3), now revised as art. 68 EECC). The 2009 EU regulatory framework broadened the set of relevant tools, with the insertion of provisions concerning "functional separation" and "voluntary separation" (also now included in the EECC, at art. 77 and 78 respectively). Among the different implementations of the ND criterion, vertical separation is clearly the most extreme and rigid, as it entails a permanent restriction to organizational freedom.

The relative importance of different provisions related to forms of vertical separation has changed through time, along with changes in technology, changes in the theoretical perception of the severity of incumbents' incentives to discriminate and changes in the objectives pursued by regulation (Krämer & Schnurr, 2014). Overall, while vertical separation has always been considered as an effective remedy to non-discrimination, a number of possible drawbacks in the form of difficulties in practical implementation and foregone economies of scale and scope has historically impeded wide recourse to this solution (Cave, Correa, & Crocioni, 2006). Indeed, differently from other network industries, in telecommunications it has been notoriously hard to draw a clear distinction between natural monopoly areas and other business areas and the risk of jeopardizing efficiencies and incentives to invest by excessively increasing the transaction costs faced by a separated incumbent has suggested caution with vertical separation remedies (Shortall, Bourreau, & Maxwell, 2020).

The 2018 EECC has marked a new turn in the swinging fate of the regulatory attitude towards vertical separation because, in addition to maintaining and revising previous rules on vertical separation, it contains an explicit favor for new entrants adopting a vertically separated business model (wholesale-only operators), which art. 80 exempts from a range of regulatory obligations. Moreover, the current State Aid Broadband Guidelines also give prominence to this sort of operators, among other things by reserving them an exclusive role as receivers of public support in black NGA areas. The wholesale-only model was originally intended as a tool useful to address potential hold-up/free-rider issue in the rollout of broadband in rural areas. However, its role has progressively assumed a broader meaning. As argued by Shortall et al. (2020), the current emphasis on vertical separation in the EECC can be interpreted as the outcome of the choice to pursue greater infrastructure competition, after a long period in which the dominant model underlying the regulatory framework has been one of service competition.

5G-induced technological change is likely to shed a new light on the recent regulatory emphasis on vertical separation for many reasons. One key technological aspect of 5G – the prospective full separation of services from the underlying network resources due to softwarization and virtualization – appears *prima facie* to facilitate forms of vertical separation. Indeed, the mentioned historical difficulties in identifying technological boundaries between retail and wholesale elements would possibly fade away in light of this

[8] Directive 2002/19/EC of the European Parliament and of the Council of 7 March 2002 on access to, and interconnection of, electronic communications networks and associated facilities (Access Directive), OJ L 108, 24.4.2002, p. 7–20.

technological development, making it easier to separate ownership and management of network resources from ownership of the complementary assets needed for service provision. Yet, vertical separation may be problematic in a context whereby investments in networks and services still need to be made.

The extreme convergence between wireline and wireless solutions as well as computing and storage resources brought about by 5G adds new dimensions to the set of technological choices to be made by network developers. In addition to deciding on the fixed network architecture and deployment modes (choosing, e.g., between point-to-point and point-to-multipoint solutions, or between FTTC and FTTH), network developers now face a wider range of options, including FWA, small cells and other wireless deployments. These technologies are linked by relationships of complementarity and substitutability and their overall value is determined by the range of applications that they may serve. For instance, it is now well accepted that there are significant cost savings (in the order of more than 20%) associated with the joint planning of the RAN architecture and of last-mile transport, so that the coordination between 5G and FTTH deployments entails significant efficiencies.[9] Moreover, 5G broadens the scope for investments in computing and storage resources that may be functional to the provision of innovative services.

This has important implications for the trade-offs involved by vertical separation in terms of investment in networks and services. Large and diversified firms tend, indeed, to be better placed to make complex technological choices of this sort because they may better spread the associated risk and because their integration into retail operations equips them with better information and better incentives to make the necessary investments. While 5G makes it easier than before to recur to market-based forms of organization, by greatly increasing the scope for downstream service innovation, it also increases the extent of economies of scope that may be obtained through vertical integration, and therefore aggravates the efficiencies foregone in presence of any mandatory vertical separation.

To make the point more concrete, consider the case of a wholesale-only operator. Firms with this organizational model, currently favoured by the EECC, have entered fixed telecommunications markets, where they enjoy regulatory advantages, and have so far not ventured into other technologies such as wireless communications. This sort of operator lacks the competences and experience of vertically integrated operators who have expanded into converged fixed-wireless offerings and it is, by consequence, less apt to make complex technological choices along the many dimensions opened up by 5G. In addition, the necessary coordination between network configuration and services is also made more difficult by a rigid application of the ND requirement such as vertical separation: in the wholesale-only scenario, any network development functional to retail innovation by a multitude of wholesale clients needs to be negotiated with the provider and it is therefore less likely to be implemented. These difficulties are compounded when the wholesale-only operator exclusively or predominantly commercializes active, bitstream-like services, scarcely compatible with downstream differentiation.

By contrast, for vertically integrated operators, the opportunity to make investments in computing and storage resources to provide innovative services may be crucial to reverse the trend of commodification of network resources that has so far jeopardized incentives to invest in high-performance networks. As it is well-known, in the past 10–15 years the emergence of Over-The-Top (OTT) service and content providers has exerted increasing cost pressure on telecommunications operators, due to the extraordinary increase in traffic they have generated, while at the same time eroding sources of revenues (Peitz and Valletti, 2015). The latter phenomenon has occurred both because OTTs have offered consumers access to services that substituted for traditional telecommunications services for free or at a fraction of their traditional price (for instance with instant messaging replacing traditional SMS services or VOIP services competing with traditional voice calls), and because they have been most successful in controlling data, emerged as the key resource for value capture along the connectivity value chain. Thus, OTTs have so far been successful in controlling the resources that are key to value appropriation, while telecommunications providers have faced increasing problems in identifying new sources of value capture that could sustain incentives to invest in networks, indispensable to value creation (high-performance infrastructures are, of course, a necessary precondition for the provision of OTT services).

5G is set to make these trends much less clear-cut than before. In particular, softwarization and the shift of network intelligence from the core to the edges may give telecommunications providers the much-needed chance to increase their ability to control and manage valuable data, redressing the imbalance that has so far favoured OTTs. As network densification proceeds, and the range of connected devices increases, operators will be able to combine radio data with a growing range of environmental, customer, population and activity data gathered through network interfaces.

More importantly, Edge Computing may give telco operators the chance to bring competition to domains that have come to be dominated only by OTTs. The extreme convergence of networks, storage and computing that we have described in section 2.1 enables telecommunications operators to invest in the provision of cloud computing services by making available processing power at the network edge. This would minimize latencies due to distance and prove particularly useful for applications in need for high-intensity data management, therefore offering users a high-performance substitute for Google's, Amazon's and Microsoft's massive scale data centers.

Thus, a number of reasons point to the fact that 5G raises the opportunity cost of addressing potential discrimination issues through vertical separation. It may be the case that 5G also influences the scope for discriminatory behaviours, prospectively limiting (at least to some extent) the traditional concerns associated with incumbents' opportunistic behaviours in managing access to the legacy network. Again, one reason why this is likely to occur is given by the mentioned technological shift towards the separation of network management and service provision. As part of this shift, associated with virtualization and softwarization, the control over data and network resources can be delocalized and becomes less dependent on the network provider than in the traditional vertically integrated

[9] See, for instance, https://www.siradel.com/research/ftth-council-europe/.

model. Key features of the quality of service, as well as additional features such as security and privacy become easier to control and customize by market players different from the vertically integrated incumbent. Which of these organizational solutions – enhanced control by telcos or delocalized management – will emerge as prevalent is hard to tell at this stage, but in both cases the importance of preserving contractual and organizational flexibility in the face of the extant uncertainty is evident.

A more indirect but not less relevant mitigating effect on incumbents' potentially discriminatory behaviours may come from the fact that 5G favours the adoption of co-investment models that tend to change the nature of Significant Market Power (SMP) issues. 5G requires considerable investments in network densification and overall transformation of the network architecture through virtualization and Edge Computing and enables massive increases in the scope of resource sharing at various levels. At the network level, indeed, we have already observed a marked shift, accompanied by favourable regulation, towards the adoption of co-investment models. The latter allow sharing the risks of the large-scale investments involved by both wireline and wireless connectivity, while preserving the possibility to offer differentiated services. In Europe, as well as elsewhere, co-investment projects are ever more widespread and are significantly reshaping market structure. The effect is perhaps more visible with regard to fixed networks, where vertically-integrated incumbents with legacy infrastructures have so far generally enjoyed Significant Market Power status, but it extends to wireless networks due to the already existing prevalence of fixed-mobile convergent business models, which is bound to increase due to 5G. Co-investment is thus likely to reduce the relevance of traditional SMP considerations, while widespread service diversification should contribute to control the opposite risk of collusive outcomes.

An additional feature of 5G networks that is likely to limit the scope of discriminatory behaviours is the fact that resource sharing, together with the commodification of many network components, is going to make it easier for a range of new players to self-provide connectivity resources. Spectrum will be increasingly shared by a variety of both licensed and unlicensed users. As argued by notable industry observers, "[t]*he 5G future will be one of many heterogeneous wireless networks under the control of many independent operators that will need to co-exist in their use of the spectrum in the same locations and at the same times*" (Lehr et al., 2021). In addition to this, as digitization advances, different end-users such as industrial automated campuses, public services or smart cities may experience a need for greater control of some network resources and opt for self-provisioning thanks to the availability of low-cost, user-friendly network equipment off-the-shelf as modular inputs. In other words, the 5G future may envisage a large number of heterogeneous new entrants in connectivity provision, thus bringing further momentum to an autonomous trend of reduction of vertical integration.

From a policy perspective, the above discussion suggests that it may be wise to reconsider early on the trade-offs involved by the *favor* the European regulatory framework currently expresses for vertically separated operators. This holds not so much for the regulatory advantages granted by art. 80 EECC, which have stimulated entry of wholesale-only operators and whose change would undermine legal certainty and jeopardize recent investments, but more so for the provisions granting advantages or even exclusivities to wholesale-only operators in the context of public investment. In particular, the 2013 State Aid Broadband Guidelines, drafted before the significant technological and regulatory evolutions that we have briefly described in this section, foresee a special role for wholesale-only operators, and even set the adoption of a wholesale-only model as one of the key conditions for compatibility of State Aid with the internal market in black NGA areas[10]. The increasing costs and declining benefits of vertical separation illustrated above suggest that such an approach should be re-evaluated in light of technological change, especially at a time where the pursuit of the EU digital connectivity targets is supported by the unprecedented funding associated with the EU Recovery and Resilience Facility.

4.2. Network neutrality

In the EU, network neutrality refers to the regulatory principle that '*providers of internet access services shall treat all traffic equally*', foreseen by the so-called Telecoms Single Market (TSM) Regulation (art. 3.3), enacted in 2015.[11] The principle, as defined in the EU, incorporates the following elements, listed by increasing degree of controversy: extensive transparency requirements; ban on blocking, throttling, and unreasonable interference by network providers; zero-price rule (network operators cannot charge a price for a specific data packet); and prohibition of traffic discrimination in terms of price or quality depending on the type, the origin or the destination of the data packet. These rules were developed initially, or primarily, for fixed electronic communication networks, but in Europe, they have been applied to the same degree also to mobile communications up to the present 4th generation of mobile networks and devices.[12]

This idea of extreme non-discrimination in the management of data packets in Internet traffic has a somewhat different origin than other non-discrimination obligations, for which strictly economic considerations tend to be dominant. Indeed, the key logical tenet of net neutrality regulation has been the idea that "general internet access" is to be preserved from likely shortages caused by the provision of preferential treatments to certain content providers affiliated with broadband providers. Consumers should be able to access the Internet with the best quality and capacity allowed by existing technologies, without being regimented or expropriated by

[10] EU guidelines for the application of state aid rules in relation to the rapid deployment of broadband networks (2013/C25/01). Official Journal of the European Union, C25, 01–26.

[11] Regulation (EU) 2015/2120 of the European Parliament and of the Council of 25 November 2015 laying down measures concerning open internet access and amending Directive 2002/22/EC on universal service and users' rights relating to electronic communications networks and services.

[12] In the US the first net neutrality regulation (FCC, 2010, Open Internet Order) essentially excluded mobile networks. In particular, the key rule of forbidding 'unreasonable discriminations' among content providers applied only to fixed networks. Later on the asymmetry for mobile networks was cancelled (see Choi et al., 2018). In Europe the 2015 net neutrality regulation applies equally to fixed and mobile networks.

the industrial interests of Major Content Providers (MCP) or of broadband providers themselves, when integrated into content provision. Thus, the primary motivation behind network neutrality rules is the protection of the fundamental right of citizens to have unfettered access to the internet - an extra-economic motivation. Ever since the concept of network neutrality was originally proposed by legal scholar Tim Wu (2004), this human rights-based motivation was complemented by a dynamic efficiency rationale premised on the idea that internet innovation is best served by the free pursuit of multiple innovation paths. From this perspective, network neutrality addresses the risk that exclusive deals for the control of large parts of the networks, negotiated between MCPs and network owners, could jeopardize innovation, diversity and competition for new entrants, especially new content providers.

Whether innovation is best served by network neutrality rules as well as whether the pursuit of fundamental rights comes at the cost of substantial static and dynamic efficiency losses are unresolved issues from the perspective of theoretical economic reasoning. The economic literature has highlighted a number of trade-offs raised by the application of net neutrality rules, finding by and large ambiguous and model-dependent results on their overall welfare effects (Easley et al., 2018). One key driver of this trade-off is the fact that net neutrality entails foregoing the efficiencies that may come from value-creating differentiated contractual arrangements, with negative effects in terms of QoS-sensitive content providers' incentives and ability to innovate and network providers' incentives to invest in networks.

In spite of the lack of a clear understanding of the welfare implications of a strict variant of net neutrality rules, the solution finally adopted in Europe with the 2015 TSM Regulation, after more than a decade of controversy, has taken a rather clear-cut stance. Two aspects of the solution are worth noting. First, it appears to reflect the idea that the defence of fundamental rights should prevail over concerns for (static and, eventually, dynamic) efficiency losses, as the pursuit of efficiencies is confined to a limited and residual space. More precisely, current net neutrality regulation allows the possibility to exploit efficiencies by providing some specialized services, but only to the extent that an acceptable quality of internet access for all is preserved. In fact the regulation, in referring to specialized services, states that: '*Such services shall not be useable or offered as a replacement for internet access services, and shall not be to the detriment of the availability or general quality of internet access services for end-users'* (art. 3.5, TSM Regulation). Thus, the current regulatory design foresees a two-tiered approach with asymmetrically regulated "walled gardens", whereby internet access services are protected from other broadband services that, on the basis of some specific criteria, can be considered private and/or distinct from general internet access (Hazlett and Wright, 2012).

The second notable aspect of European net neutrality regulation relates to the fact that it has been crafted in very technology-dependent terms. Indeed, the choice to reserve a residual space for broadband access services whose characteristics can be freely negotiated between network providers and content/service providers reflects the particular balance between citizens' unimpeded access to the internet and efficiencies that is associated with a specific technological environment – one in which absent a distinction between "general internet access" and "specialized services" the minimum acceptable QoS threshold that guarantees citizens' fundamental rights cannot be met. This, however, only occurs if scarcity of bandwidth is severe enough. If technological change were to alter this scarcity condition, the minimum acceptable QoS threshold could be met without the need for "walled gardens" and the terms of the trade-off would change. Such technological change is precisely that entailed by 5G.

We believe the advent of 5G should trigger an update of the current European variant of network neutrality. In a nutshell, the fundamental rights justification for net neutrality is not as stringent as before in a context of significantly increased capacity, while the efficiency losses from constraining contractual freedom are magnified. The application of strict, technology-specific non-discrimination rules appears to give rise to an unfavourable cost-benefit balance and ways to allow for service differentiation while guaranteeing substantial non-discrimination should be found.

As suggested in section 2, the constraints posed by limited capacity are likely to be alleviated in the prospective 5G world of massive system capacity. On one side, the technological developments described in section 2 (and the ones that will follow 5G) promise to substantially increase the efficiency in the use of available resources, thus ensuring easier access to capacity. On the other side, similarly to what has happened for cloud computing, barriers to entry to the infrastructure layer will be significantly lowered by the fact that the shift towards software-defined networks, where different functions can be abstracted and provided over the same common physical network, will increase the availability of standard components that can be easily acquired from a variety of providers. Thus, supply of network services is going to increase and to come from a variety of sources. The scarcity logic will therefore be less stringent than before.

If band capacity is less likely to pose a binding constraint, the risk of throttling final consumers' access to the Internet is greatly diminished, and the need for a specialized protective regulation is greatly reduced. More than that: the rationale for preserving "general internet access" at the expense of efficiency is undermined when the minimum QoS threshold compatible with a reasonable interpretation of the fundamental right of access to the internet can be met without creating walled gardens. If this is going to be the case with 5G, as it currently appears likely, priorities should be reversed: scarcity is sufficiently alleviated to suggest that emphasis should be placed again on the traditional economic considerations suggesting that resources should be allocated to the uses that (dynamically) maximize their value. From this perspective, what needs protection is the possibility to ensure the guaranteed QoS essential to new applications through service differentiation.

In any case, the former is not the only or even the main reason why net neutrality regulation is falling under the pressure of 5G disruption. The very distinction between general internet access and specialized services becomes difficult to pin down, as the concept of network slicing makes it hard to perform meaningful comparisons among the services provided. In the face of a plurality of virtual networks that can be configured and rented for delivering a variety of different services, clients will soon become sort of 'tenants', temporarily owning their own network. In this situation, the conventional notions at the basis of any non-discrimination analysis and at the core of the present network neutrality regulation, QoS included, will rapidly lose significance. The use of a common infrastructure for offering contemporaneous services to different industries vividly illustrates the technology-dependent nature of current net neutrality rules.

Starting from these premises, also the consideration that the present European network neutrality regulation is formulated with sufficient flexibility to accommodate new services, because it contains a concept of "*optimized*" services that can be offered to meet "*a specific level of quality*" (art. 3.5, TSM Regulation) appears misleading. The idea of optimized services hinges on the existence of a common benchmark and especially on the need to preserve a distinct basic common service of access to the Internet. However, from the perspective of 5G verticals, the distinction between general internet access and optimized services becomes obsolete, along with the trade-off inspiring the regulation.

What is more important, the new technical flexibility translates into economic possibilities that, especially in presence of significant uncertainty, can be turned into expanded output and innovative applications only to the extent that flexible contractual solutions allow to align the interests and incentives of all the parties involved. It is this contractual flexibility that will allow the creation of the 'verticals' and of the new applications we introduced in section 2.2, the configuration of a plurality of physical, virtual and service layers that combined in different manners – all using the same "network" – will provide completely different services to different users and enhanced economic value to those who invest in their provision. In a world whereby scarcity is alleviated and entry of service providers of any size and typology may easily occur through access to a set of scalable network resources (much as it has occurred in the cloud with computing resources), decentralized innovation appears best served by contractual freedom rather than by rigid ex ante rules imposing uniform treatment of widely different service providers. In this context, non-discrimination has still a space as a general rule ensuring that firms in the same position enjoy equal treatment, but the view of non-discrimination as absence of differentiation in terms of either quality or price appears to be more evidently at odds with efficiency considerations than before.

As a final point, it is worth briefly commenting specifically on the issue of the incentives to invest in networks in the face of the changing nature of scarcity issues in the presence of 5G-induced technological change. Two traditional arguments in favour of constraining network providers' contractual freedom through net neutrality regulation are, on one side, the idea that network providers may have incentives to favour their own content and, on the other side, the hypothesis that allowing for some form of data packet discrimination would enable network providers to strategically keep network capacity scarce by withholding investment in order to profit from prioritization (Krämer et al., 2013). Both arguments appear significantly weakened by the advent of 5G. The first is controversial, as it could be considered not particularly stringent even in the context of the historical net neutrality debate in light of the complementarity between networks and services. The latter suggests that network providers tend to have incentives to increase the joint value for consumers of the network-services bundle (or, in the language of multi-sided markets, the overall extent of network effects). In presence of multiple competing and convergent networks and of less stringent capacity constraints, it is even harder to see how NPs could profit from discriminating in favour of their own services. Relatedly, increased competition may also jeopardize any strategic incentive to withhold investment. However, a problem with network investment may still remain and be aggravated, rather than alleviated, by strict network neutrality rules of the sort currently in place. The problem is compounded by the fact that the bulk of value creation from 5G investments seems to come from B2B relationships, considering the apparent reluctance of customers to pay for improved mobile connectivity (Yoo and Lambert, 2019). Rigid limits to service differentiation and the associated pricing flexibility limit the ability to reap these benefits from network investments. From this point of view, the current variant of EU network neutrality regulation would thus also appear to be at odds with the recent emphasis on investment embedded in the evolution of telecommunications regulation, as reflected, for instance, in the EECC.

To sum up, network-level ND rules are subject to much less ambiguity than the ND requirement in SEPs licensing. We have discussed two of these rules that are particularly rigid and technology-dependent: the *favor* for vertically separated organizational forms and the current variant of network neutrality rules. We conclude that, with the advent of 5G, these particularly inflexible declinations of the ND principle may have negative effects on the maximization of the overall value of digital information systems, because they prevent value-enhancing organizational and service differentiation and are based on an obsolete view of the relevant scarcity issues.

5. Technological neutrality regulation and incentives to invest in networks

A different sort of non-discrimination prescription is given by technological neutrality, which directly concerns regulators and policymakers, rather than market players, although its application indirectly influences network operators' investment choices. Technological neutrality has been a principle of the European Electronic Communication Regulatory Framework ever since 2002 and it has been recognized as a key principle for Internet policy by other international fora (OECD, 2011). While it may be interpreted to have multiple meanings (Maxwell and Bourreau, 2015), in this paper we refer to the one underlying the explicit reference made to it in the Framework Directive (Recital 18): *"[t]he 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 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."*

The passage clarifies that the principle of technological neutrality is meant to prevent the distortions that may be involved by regulators' (and, by extension, policymakers') attempts to influence the evolution of particular markets by picking technological winners. The rationale for this is, of course, that market players normally have both better information and greater incentives to make the most advantageous and future-proof technology choices. Thus, the greater the uncertainty surrounding the technological evolution of markets, the greater the benefits from adhering to the principle of technological neutrality.

Recital 18 also highlights that this principle is not intended as absolute and essential, but rather "desirable" and subject to the possibility that it could be sacrificed in the pursuit of other policy objectives. Indeed, as any other declination of the non-discrimination criterion that we consider in this paper, also the technological neutrality principle involves trade-offs. On one side, as mentioned, the principle ensures benefits in the form of better exploitation of the technological information available to private parties and in terms of avoidance of the risk of distortion of incentives to invest due to incorrect predictions on future-proof technologies. On the other side, however, adherence to the principle of technological neutrality entails missing the opportunity to address at least two forms of market failures.

The first “missed opportunity” stems from the fact that expressing a specific policy preference for given technologies may help to solve coordination and externality problems that slow down their development. This reasoning has featured prominently in the debate on the appropriate regulatory and policy tools to stimulate the deployment of Very High Capacity Networks (VHCN) in Europe[13]. According to some, there is a wide range of externalities associated with investments in VHCN. A public commitment to VHCN may induce private operators to (at least partly) internalize them. From this perspective, abandoning the principle of technological neutrality would bring more benefits than costs and therefore be justified because some specific technological solutions (and particularly FTTH) are clearly future-proof and allow to maximize the stream of future welfare gains from investment for society at large.

The second form of potential market failure is more subtle and relates to the fact that operators with Significant Market Power (SMP), owners of legacy infrastructures, may distort competitors' investment choices through their own technological choices, with the aim of entrenching their dominant position. Cave and Shortall (2016) have highlighted this possibility, with reference to the choice between FTTP and FTTN and between point-to-multipoint and point-to-point architectural solutions. In both cases, the first option would grant competitors a wider set of technological options and strengthen their ability to develop a more infrastructured access model, and is, therefore, less compatible with incumbents' strategic considerations. From this perspective, deviations from the principle of technological neutrality would be more compatible than its strict application with the objectives of preserving a level playing field among alternative technologies, preventing distortions of competition among players in the fixed connectivity markets and curbing incumbents' market power. Thus, the costs of applying technological neutrality increase with the extent of the externalities associated with investment in new technologies and with the risk of competitive distortions induced by SMP operators' strategic behaviours.

How does 5G impact these trade-offs? Let's consider the benefits and costs of technological neutrality in turn. On the benefits side, one aspect clearly stands out: the major driver of the benefits from technological neutrality – uncertainty – is undeniably significantly raised by the advent of 5G, as mentioned in the Introduction. In the context of investments in VHCN, this amounts to the expansion of the range of future events firms face (e.g., possible future business models, technological paths, innovative services). Even limiting attention to the network level (types of FTTx implementation, architectures, wireless vs. wireline technologies), technology choices require speculations on a much wider range of possible scenarios than those that have so far been considered in network building.

This brings us to the second aspect of 5G that we think will increase the benefits from maintaining a strict technological neutrality principle: the increased complexity of technological decisions in presence of changing relationships of complementarity and substitutability among different technological solutions. As briefly illustrated in section 2.1, fiber and 5G wireless solutions are both complements and increasingly substitutes one for the other. FTTH backhaul is key to deliver the benefits of wireless installations, and therefore FTTH and small cells are certainly complementary technologies whose joint deployment may allow for significant cost savings. The nature of the complementarities is also changing. In addition to the standard complementarity whereby cellular traffic is offloaded on fiber-based Wi-Fi connectivity as soon as possible, fixed broadband providers are likely to increase their reliance on a model whereby data traffic on fixed networks is offloaded on cellular networks to support increased speed or coverage needs.[14] The constraints to the substitutability between wireline and wireless solutions are also fading away because of 5G, as wireless networks come to provide levels of speed and capacity that rival and possibly outweigh fixed connectivity in a not-so-far-away future.[15] The evolution of the relationship of complementarity/substitutability between FTTH and wireless solutions is therefore fraught with uncertainties and any explicit policy preference for a given technology would certainly run the risk of inducing significant distortions.

Things are less clear-cut on the “cost side” (or, perhaps, “foregone benefits side”) of the application of the technological neutrality principle. In particular, the effects of 5G on the externality market failure rationale for abandoning the technological neutrality principle are ambiguous. One possible view is that the benefits from specific network investment choices - i.e., FTTH - have increased sufficiently, due to the complementarity between FTTH and 5G network implementations, to make abandonment of the technological neutrality principle worthwhile (Briglauer et al., 2020). A possible interpretation of this view is that the benefits from 5G can be

[13] The debate has seen EU institutions willing, at times, to explicitly forego application of the principle of technological neutrality for the sake of pursuing ever more challenging network deployment targets. The final solution preserves the emphasis on VHC networks, but the preference for FTTH solutions is not expressed explicitly and is, instead, embedded in the nature of the connectivity targets set in different policy documents.

[14] This is a form of enhanced fixed-mobile integration that Lehr et al. (2021) report to be implemented by Comcast and Google's connectivity services.

[15] Whether 5G will outweigh fixed connectivity will depend also on the technological evolution of fibre. For instance, Dense Wavelength Division Multiplexing (DWDM) is already used to increase the bandwidth of existing fiber networks. Moreover, the capacity of fiber-based networks can be easily increased by adding additional fibres at marginal cost. The point we raise here concerns exactly the existence of technological uncertainty.

considered an additional, extremely relevant, externality associated with FTTH investments, one that significantly strengthens the case for considering FTTH a "future-proof" technology.[16]

Other aspects of 5G lead to opposite conclusions. The increased scope for service provision and applications complementary to converged wireline-wireless networks may be interpreted to entail a broader scope of value capture for investments in networks, including FTTH deployments. From this perspective, the increase in the benefits of FTTH can be seen to mitigate the incentive problem that abandonment of technological neutrality is meant to solve. In other words, 5G not only increases the positive externalities associated with FTTH (and other) investments, but also the benefits that can be appropriated by those making network investments. It is therefore not at all clear that the externality market failure problem increases due to the advent of 5G. To this it should be added that the increasing scope for resource sharing offers a chance to rationalize and reduce the costs of investments, thus further mitigating the incentive problem.

As for the costs due to the inability to address the market failure linked to incumbents' attempts to distort competitors' technological choices, we believe the impact of the evolutions associated with 5G is clearer and goes in the direction of limiting these costs. 5G requires investments on a very significant scale. Also, the deployment of small cells as well as other 5G-related deployment may have a sizable environmental impact. These factors, together with the increased technological scope for resource sharing, have pushed many telecom operators towards various forms of co-investment. This, in turn, changes the nature of the SMP considerations at the heart of Cave and Shorthall's (2016) reasoning. By its very nature, co-investment limits ex post market power by increasing competition at the very moment the investment is made. Moreover, technological choices are decidedly more independent from incumbents' strategic manipulation, as they are shared among two or more players, are normally reviewed by competition authorities and possibly compliant with art. 76 EECC, which is carefully crafted to ex-ante rule out competitive distortions. In contrast, since 5G changes competition at different levels of the value chain, it may well be the case that abandoning the principle of technological neutrality at such an uncertain and disruptive junction could lead to competitive distortions in many unforeseen and undesirable ways.

6. Conclusions

The present paper has explored the impact of 5G-induced technological change on the interaction among different regulatory instantiations of the principle of non-discrimination and innovative investments in basic technologies, networks and services. By focusing on the implications for market and competition dynamics along the value chain that are most likely to be impacted by the new technology and by jointly analysing different levels of the value chain, it has attempted to uncover some common themes. The analysis has necessarily been highly speculative, due to the inevitable uncertainties on the effective evolution and impact of 5G. It is nonetheless essential to consider early on the implications of the different variants of non-discrimination rules that may affect incentives to make innovative investments, to be able to timely adjust policy and regulation to the new trade-offs associated with technological change. 5G enables the development of a wide range of new services and applications, but the full realization of these benefits for end-users will swiftly materialize only provided that fully converged wireline and wireless networks are put in place. Also, continued innovation at the technology component level depends on the solutions that will be devised to find a balanced incentive structure for upstream technology developers and implementers through FRAND licensing terms.

Technological change affects the relevance of the different non-discrimination problems that may arise, and the associated trade-offs, because it tends to influence market structure and with it the extent of market power, the nature and accessibility of the resources that are key to competition, barriers to entry, the scope for value creation through the combination of multiple resources, and the nature of production. In the face of these changes, and their associated uncertainty, it appears very important to refrain from overly rigid and technology-dependent interpretations of ND requirements. This holds for the institutional arrangements for the licensing of standard-essential patents, based on the concept of FRAND licensing, that are under strain for 5G standards, as the traditions of industries organized in widely different ways enter into conflict. Furthermore, downstream in the telecommunication industry, 5G's challenges to the clear distinction between wireless and wireline networks call for a redefinition of the old threats to non-discrimination caused by traditional vertical integration in fixed networks and, therefore, for a re-examination of mandatory access and network separation regulatory solutions. At issue also appears to be the standing of net neutrality regulation, which may soon turn out to be an obsolete and counterproductive answer to a problem of band scarcity and prioritization that is profoundly transformed by increased capacity and network slicing.

Finally, we expect that, notwithstanding some hesitations of the EU Commission in the past years, the disruptive impact of this new generation of mobile connectivity ultimately will strengthen the case for technological neutrality, inducing legislators and regulators to greater caution in front of an increased technological uncertainty of a Knightian nature. Picking technological winners in the face of increased uncertainty remains a very poor idea that should and will very likely be avoided.

[16] Briglauer et al. (2020) agree with the view that the differential external benefits generated by VHC networks with respect to standard broadband networks are not high enough to justify abandonment of the technological neutrality principle (see, e.g., Bertschek et al., 2016; FSR, 2017; Abrardi and Cambini, 2019). However, they consider that including the benefits from 5G in the cost-benefit calculus changes the conclusion, leading benefits to exceed costs. Among the latter are the missed opportunity to exploit the information privately available to firms on the best technological solutions, reduced flexibility in the face of uncertainty, and the possibility that the increased public funding associated with the pursuit of non-technologically neutral targets may distort and/or crowd out private investments (Parcu & Rossi, 2020).

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