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The future of 5G and beyond: Leadership, deployment and European policies

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ABSTRACT

This paper discusses the need for a strategic rethinking of the policies that promote 5G development and deployment in Europe, as they are crucial in determining the future impact of 5G and later also 6G on the digital economy. Considering the current state of 5G deployment and insights that have emerged from the debate on 5G technological leadership, we discuss the need for a more effective and proactive policy from the European Union in this field. The main suggestion is to develop an industrial policy that contrasts fragmentation in the telecommunications sector by taking the whole European Union as the scale of action, instead of just the individual member states.

1. Introduction

Few years have passed since the first fifth generation (5G) mobile network was deployed in 2019. Increasingly capable of connecting not only people, but also machines and objects, 5G is clearly emerging as a new global standard. Despite its still ongoing deployment and adoption, mobile network technology keeps evolving: several improvements to 5G are being introduced while the sixth generation (6G) is already being developed (Dang et al., 2020; Heikkilä et al., 2023; Ojutkangas, Rossi, & Matinmikko-Blue, 2022). In any case, 5G cannot be considered as a simple improvement with respect to previous mobile technologies (Suryanegara, 2016). This is because it introduces not only incremental changes (i.e., increased speed and lower latency in data transmission) but it also has new features which will enable radical changes that will improve interactions between machines (even without direct human agency) and increase the relevance of edge computing (Ren et al., 2019). Due to these new features, 5G technology is already accelerating the digitalisation in many areas, and thus influencing a plurality of sectors (Campbell et al., 2017; Cave, 2018; Rao & Prasad, 2018). In fact, the success of the Internet of Things (IoT), which is often called the next Industrial Revolution, and the expected rise of the Metaverse, are heavily dependent on the development and deployment of 5G, and eventually also of 6G.

According to the latest data, at the end of 2021 there were already more than 11 billion IoT devices connected and by 2025 this number is expected to rise to almost 20 billion (Statista, 2023). The economic impact of 5G and its evolutions is expected to be huge, producing up to $13.2 trillion in revenue growth and creating up to 22 million jobs by 2035 (Rastogi, 2022).

Given these estimates, and all the new features of the last generation of mobile networks, it seems clear that the expected changes will go well beyond the telecommunications industry (Cave, 2018). However, it is still unclear which sectors will be most affected by 5G: while some are already appearing with the first usage of the technology, others will become clear through the growing use and 5G will likely cover more areas than expected (Campbell et al., 2017). This is already partly happening with the gaming industry, and the

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still underexplored usage of the Metaverse. Additional use cases and opportunities will surely appear also in the sectors where the deployment of innovations is already solid: vehicles automation, smart home (Aazam et al., 2018; Knieps, 2017), smart agriculture, industrial manufacturing, healthcare, and automation for logistics (Anwar & Prasad, 2018; Knieps, 2019).

It seems worth noting that in the already mentioned Metaverse, the importance of the mobile network infrastructure is largely recognised. In fact, many studies describe the Metaverse as divided in seven different layers (Radoff, 2021). The base layer comprises the technological *infrastructure* of the Metaverse that makes possible all the higher layers. This basic layer necessarily includes connectivity technologies, in particular telecommunications networks, where certainly fibre but also 5G and 6G are expected to play a key role, alongside with cloud systems and semiconductors. A critical issue for the Metaverse relates to latency, which is why 5G and following evolutions of mobile technology are crucial for improving the immersive experience: they can offer the necessary speed and latency and, in contrast to fiber, can also be used on mobile devices.

Considering the wide range of applications and the expected relevance of some of these fields (IoT, Metaverses, AI, cloud and edge computing, etc.), its worldwide spread and large-scale adoption, 5G and following evolutions may emerge as a general-purpose technology (GPT) (Heikkilä et al., 2023; Parcu, 2022; Parcu et al., 2022), thus becoming as disruptive as personal computers and the Internet had turn out to be years ago. A technology can be defined as a GPT when it shows three main features: 1) it must be ubiquitously diffused (i.e., spread across many sectors of the economy); 2) it should enable new processes of innovation; and 3) it should be characterised by fast evolution (Bresnahan & Trajtenberg, 1995; Knieps & Bauer, 2022). The emergence of 5G as a GPT is crucially connected to its future diffusion, which in turn depends on its adoption as the new universal standard for human mobile communication and machine-to-machine communication. In this respect, the standard-setting institutions will play a pivotal role in favouring and fostering 5G's worldwide diffusion. Considering the relevance of 5G technology, the debate surrounding leadership in its development and roll-out is quite heated and revolves around two main issues: industrial and/or geopolitical leadership in technological innovation (Parcu et al., 2022; Teece, 2021), and the challenges related to 5G's deployment around the globe. A question that emerges in the context of this debate is whether a novel 5G-focused EU industrial policy could close the present gap in technological leadership and deployment.

In the remainder of the paper section 2 presents the methodologies used to assess the technological leadership on 5G and summarise the results of the current literature on the topic. Section 3 focuses on the state of 5G deployment in Europe. Section 4 is dedicated to evaluate if there is the need to develop an EU industrial policy to foster technological leadership and deployment. The last section concludes.

2. Leadership in 5G technology: the state of the art

Previous literature regarding the technological advancements in 5G and the early development of 6G, clearly showed that these technologies are basically led by the United States and China (Buggenhagen & Blind, 2022; Mendonça et al., 2022; Parcu et al., 2022). The assessment of the leadership in the technological development of such a relevant technology is not just a mere theoretical exercise. It is essential for understanding what type of policies may need to be developed in Europe or in other regions to catch-up or to maintain a privileged position in the development of 5G and subsequent connectivity and mobile technologies.

Previous works have followed different methodologies to investigate technological leadership in 5G and the early development of 6G. Analysing a set of collected papers focused on 5G leadership,[1] we identified the following as the most debated issues.

- the correct database used to extract the patents or contributions,
- the identification of main patents related to 5G, and
- the different methods used to define the leadership.

All these issues have their roots in many and multifaceted theoretical and empirical studies. First, the choice of databases is quite controversial. While some studies use a selection of Standard Essential Patents (SEP), mainly through the use of ad hoc databases (ETSI), other use data from one or more patent offices (such as CNIPA, EPO, JPO, USPTO, WIPO). Each of these possibilities has its own strengths and weaknesses, as the choice to use one or another database may lead to different results. ETSI database, for example, includes only patents that are declared as essential to the 5G standard, but the assessment of "essentiality" is still fiercely debated (Bekkers et al., 2022; Contreras, 2017) mainly because the well-known problem of over-declaration (Brachtendorf, Gaessler, & Harhoff, 2023). Moreover, merging different databases might create important methodological difficulties.

Second, also the identification of the patents related to 5G is not a straightforward exercise. Some studies identify 5G patents referring to technologies (Santoalha & Boschma, 2021),[2] other using keywords (Xie & Miyazaki, 2013), while some others yet mix the two strategies (Benson & Magee, 2013) or use databases that have already selected the patents related to the technology.

Finally, regarding the methods used to define the relevance of patents, and thus deriving the leadership, in the literature on innovation we may find very simple methods, such as the mere counting of patents (Johnstone et al., 2012), as well as more complex ones: i.e. the number of technological classes involved in every patent, the citations received (Innocenti et al., 2022), the value added

[1] The collection was made using the most renowned scientific databases (Web of Science, Scopus and scholar) and identifying a first core of studies that investigate the leadership in 5G technology. Next, we have also checked the references of these studies to include other studies that were missed in our first search.

[2] Usually, using IPC or CPC technological categories assigned to all patents.

to the company stock (Nicholas, 2008), or to other composite indexes (Schettino et al., 2013). Of course, the precise subject and timing of the study also determine the best choice among methods. For example, the number of patents' citations, which is a commonly used method in assessing the quality of patents, cannot be easily used since 5G is a recent technology and, therefore, it appears premature to adequately evaluate patent quality through citations. However, what seems relevant is to identify appropriate methods capable to overcome the simple number of patents, that clearly does not represent the technological leadership of a country as it does not account for the quality or relevance of the patents owned (Parcu et al., 2022; Teece, 2021; USPTO, 2022).

Table 1 summarises some of the most recent empirical papers on technological leadership on 5G. We selected them for offering an overview of the different methodologies, approaches and data, the (patent or contribution) identification strategy, and the main results achieved regarding the leadership.

It is a fair synthesis of these studies, to conclude that the technological leadership on 5G appears firmly in the hands of the US and China. None of the considered studies, irrespective of the use of widely different data and methodologies, finds Europe as the leader in the 5G technology. However, when the analysis is developed using advanced methodologies that investigate the "quality" of the 5G patents by considering the firm or the country portfolio, the picture appears slightly different and less negative for the EU. According to Parcu et al. (2022), while single European countries are clearly far behind the US and China, the EU, if considered as a whole (EU 27), appears closer to the US and almost at the same technological level as China. This would suggest that if the EU member states decided to cooperate in a strategic way through an integrated effort in such a relevant technology, they could be considered as a credible competitor with respect to both the US and China.

As previously mentioned, the extent to which 5G will deliver the expected socio-economic benefits on a global scale will strongly depend on the existence and efficient functioning of those institutions that enable and facilitate global cooperation in its development, and particularly, on the worldwide adoption that is favoured by Standard Development Organisations (SDOs). Strengthening the standard-development process, as well as facilitating access to its results, has become a priority for the EU, as was stated in a recent communication from the Commission that launched the EU Strategy on Standardisation (European Commission, 2022a).

Notwithstanding the absolute necessity for the EU to be at the technological leading edge of such an important technology, the development of the standardisation system will, in any case, offer a global opportunity to use and implement 5G. What therefore seems at least as critical and urgent for the EU in the next few years is the timely deployment of the new networks in step with the evolution of the technology. However, as the next section will discuss, also the deployment of 5G networks in Europe is lagging behind, due to the challenges related to investment in what appears, to be a quite fragmented landscape, if compared with the other regions of the world (Lemestra, 2018; Blackman & Forge, 2019).

3. The slow deployment of 5G in the EU

The enthusiasm of European policymakers in setting ambitious targets for 5G deployment in Europe has to face the challenges of an implementation that is proving significantly slower than expected (European Court of Auditors, 2022; GSMA, 2021). The most recent formulation of these targets can be found in the 2030 Digital Compass, launched by the European Commission's communication of March 2021 (European Commission, 2021), in which the contribution of "secure and sustainable" infrastructure to the digital transformation of Europe is articulated in targets - to be reached by 2030 - related to connectivity (Gigabit for everyone), semi-conductors (double EU share in global production), data, edge, cloud (10,000 climate-neutral highly secure edge nodes) and computing power (first computer with quantum acceleration).

While a first target of having fully commercial 5G services in at least one major city per member state by the end of 2020 has by now apparently been completed for all EU-27, the latest report by the European 5G Observatory (October 2022a), in charge of the official monitoring of the progress against targets, identifies a series of bottlenecks with respect to the actual performance.

Amongst the main EU connectivity targets are the provision of uninterrupted 5G wireless broadband coverage for all urban areas and transport paths by 2025 and 5G coverage of all populated areas by 2030. According to official data, the overall 5G coverage has now reached 72% of the EU population.[3] This is quite lower than the numbers reported by the European Telecommunications Network Operator's Association (ETNO), with respect to the performances of other regions of the world: nearly 96% 5G coverage in the USA, 95% in South Korea, 90% in Japan, and 86% in China.[4] Even considering that 5G coverage statistics may not be fully comparable because of the different contexts, technologies adopted, and typology of spectrum bands assigned, these data confirm that the EU is lagging behind its major competitors. Moreover, it must be noted that even the interpretation of the official data on EU 5G deployment is not straightforward (European 5G Observatory, 2022b).[5]

First, there is a lack of uniformity in reporting from the member states in terms of the expected quality of services (minimum speed and maximum capacity), but also in terms of basic information (for example, coverage of major roads and railway is only reported by Finland). In other words, the 72% coverage presently declared for the whole EU does not assure any specific quality of service. For the future, the Commission has developed a common monitoring mechanism, presented in the context of its 2030 Policy Programme "Path to the Digital Decade", which should offer a reasonable solution to this issue.

[3] Broadband coverage of rural areas remains challenging, as 8.5% of households are not covered by any fixed network, and 32.5% are not served by any NGA technology. However, 4G is widely available in rural areas (99.6%), see Report 5G Observatory - October 2022.

[4] https://5gobservatory.eu/etno-says-europes-5g-rollout-is-lagging-behind-global-peers.

[5] See the 5G Observatory Report published in January 2022b on the problems of measuring 5G deployment consistently across countries and operators.

Table 1
Overview of the main contributions on 5G technological leadership.

Contribution	Data	Identification strategy	Method	Main results
Buggenhagen & Blind, 2022	Publications, patents and standard WoS and Iplytics Assignee and country Until March 2021	Patents classified by Iplytics as 5G relevant. Publications through keyword-based topics.	Number of patents, standard and publications as well as weighted number (splitting the value by the number of contributors).	The countries leading in patenting and standardization are particularly the Asian countries (China, Korea, and Japan), the European countries (Sweden and Finland), and the US. Even if China and the US are the leaders, publishing is much more globally distributed and not as concentrated.
Mendoca et al., 2022	Publications WoS Country 2005–2020	Publications mentioning "5G" in the title, abstract or keywords.	Number of publications and citations by country and institution. Network analysis for collaborations	The rise of 5G was driven by China and the US. During this evolution, the country composition became more diverse and other upper-middle (besides China) and lower income (like India or Pakistan) countries have become active contributors.
Noble et al. (2019)	Patents families ETSI database Company Until April 2019	Patent families or applications declared to 5G standard.	Different metrics, raw declarations and essentiality scores added to declarations drawn from *Unwired Planet.*	The main goal of the study is to show that the results are extremely sensitive to the metrics used, thus an accurate identification and explanation of the quality or essentiality is particularly relevant.
Parcu et al. (2022)	Patents USPTO and EPO Country 2010–2019	Literature and co-occurrence analysis to identify the technologies and keywords to select the patents.	Technological complexity (Hidalgo & Hausmann, 2009)	The US appears to lead, followed by China, Japan and Korea, while Europe is lagging behind. However, when looking at geographical regions instead of single countries, Europe is close to Asia and both are not too far from America.
Pohlmann et al. (2020)	Patents IPlytics based on ETSI Company and country Until December 2019	Based on the technical specification following the 3GPP or project description "5G" or "New Radio"	Several metrics regarding patent families (numbers, normalized numbers, forward citations)	Chinese and Korean companies lead, followed by European and US companies. However, when weighting for countries where the patent is filed, US companies appear as leaders. Finally, regarding forward citations the results are more diversified

Second, it is important to distinguish between the various frequencies on which 5G operates - low-band, midband and high-band - because achieving the full potential of 5G also depends on delivering speeds significantly higher than 4G, which is possible only in higher frequency bands like 3.4–3.8 GHz (midband) and 26 GHz (high-band). The sub-1 GHz bands, like 700 MHz, are essential for wide areas and indoor coverage but result in reduced download speeds if compared to 5G in 3.6 GHz band. The 26 GHz, on the other hand, provides high speed 5G but only in very high-density locations (because of the very limited characteristics of this frequency band). For this reason, 3.6 GHz is considered as the crucial frequency for offering high speed 5G to consumers.

In the EU, the 3.6 GHz spectrum band has been the most widely assigned: 25 out of 27 Member States have completed the assignment of this band, assigning almost 84% of the available spectrum, with Estonia and Lithuania making the most notable progress with respect to the previous period considered by the 5G Observatory Report. In contrast, due to the lack of demand for the 26 GHz (see Plum Consulting, 2021), this band has been assigned in only 8 countries (in total, less than 30% of the available spectrum in this band was assigned in the EU).[6] The fragmented approach adopted by EU countries for spectrum assignment has been identified as one the main problems for the 26 GHz band (see, for example, the difference between the choices made in Germany and in Italy, Report 5G Observatory 2022a).

More generally, observers have often pointed to the very high prices as one of the main problems in spectrum auctions in the EU (Kuś & Massaro, 2022). High auctions' prices make it more difficult and unlikely for new players to enter the market and, above all, as stated by many mobile network operators (MNOs) globally, necessarily imply fewer resources to invest in 5G deployment, and therefore, delays in the effective rollout of the network. However, the average prices paid (at least for mid-band spectrum) in Europe are not especially high, if compared to those in Canada and the US. The most significant issue seems instead the great variability of prices across EU countries, with Italian operators paying eight times more per megahertz than Finnish operators (ETNO, 2023). This fragmented approach to spectrum policies is an obvious issue for a homogeneous European deployment.

Conversely, there are positive expectations that the recently proposed Gigabit Infrastructure Act[7] will make the rollout of networks faster and cheaper by reducing administrative costs and burdens, streamlining and digitising permit procedures, facilitating the joint use of physical infrastructure, and fostering the deployment of fibre networks. In addition, the Commission also announced a Gigabit Recommendation, which will provide guidance to National Regulatory Authorities on how to use the tools at their disposal to

[6] The 8 countries are: Croatia, Denmark, Finland, Germany, Greece, Italy, Slovenia, and Sweden (85%).

[7] The Gigabit Infrastructure Act Proposal has been published on 23 February 2023, and can be accessed at: https://digital-strategy.ec.europa.eu/en/library/gigabit-infrastructure-act-proposal-and-impact-assessment.

incentivise faster network deployment.[8]

Concerning the 5G diffusion, according to GSMA data,[9] in 2021 5G technology accounted for only 4% of the market in Europe, whereas 4G still dominated, representing 75%, while 3G and 2G still accounted respectively for 15% and 6%. One interesting forecast presented by GSMA (2022) is that, while 4G is expected to continue to grow in developing markets, particularly in Sub-Saharan Africa, globally 5G will account for a quarter of total mobile connections by 2025, more than three times the figure for 2021. This process of "tech migration" has already started, with 4G adoption beginning to decline. The transition, however, is happening at different speeds, with 5G becoming mainstream only in a handful of pioneer markets (notably China, South Korea and the US, see ERT 2020). Another important element to consider is the architecture of 5G technology deployed, whether it is non-standalone (NSA) or standalone (SA), keeping in mind that only the second type of roll-out makes it possible to achieve the full capabilities of 5G. While operators around the world have normally started from non-standalone (NSA) versions of the technology, standalone 5G (SA), which is key to supporting applications based on enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC) and IoT use cases, is now finally launched everywhere around the world.

As for Europe, according to the data collected from the 5G Observatory on the commercial launches of 5G, the majority of 5G commercial offers were launched by European operators in 2020, but it is only in 2022 that standalone launches have reached a more significant proportion with respect to the total (38%, see Fig. 1). However, commercial launches of standalone 5G are still concentrated in a few countries, with Germany far ahead of the rest of the EU (Fig. 2). According to ETNO (2023), the Asia–Pacific block leads in terms of the number of 5G standalone services, with 15 active services. At the time of writing, Europe has 4 SA active services (one more than in the previous year, but some operators have announced SA launches for the second half of 2023) and North America has 3.

While the deployment of 5G technology will undoubtedly continue to evolve in the next few years, initiatives on 6G technology and related standards have already been launched all around the world, with Europe also committed to contributing to the development of the future generation of mobile communications.[10] For what is known today, 6G will use cognitive technologies like AI to enable high-speed/low-latency communication aiming at speed and latency highly superior to 5G networks.

According to experts, one of the challenges of 6G will be related to the design and production of chips that can be sufficiently energy-efficient in the frequency ranges of the relevant bands. Already with 5G, energy efficiency is a top priority for most telecom companies: while 5G networks are intended as key enablers in achieving sustainability thanks to "smart" applications, its denser base station infrastructure, the use of higher frequencies, the need for larger amounts of storage, are all factors that drive up energy consumption. However, both 5G and, even more, 6G networks[11] carry the expectation to be a key contributor to a more sustainable future. The scarcity of public evidence concerning the energy consumption of 5G in the EU limits the possibility to effectively gauge if, in its concrete deployment, its energy saving potential is actually realised in practice (European Commission, 2022b; Williams et al. 2022).

4. Is there a need for a new EU industrial policy on 5G networks?

4.1. The general thread

5G (and 6G) is not simply another consumer-focused mobile broadband service, but a technology that is a part of a wider ecosystem, and which has the potential, already now and with its evolution, to become a GPT. The fact that 5G creates a more extensive and complex ecosystem implies both at the policy and company level that coordination costs are higher given the increasing number of interdependent players (with potentially conflicting, or at least not fully aligned interests), who need to produce a closely integrated service in a more differentiated value system. Hence, to ensure that 5G can fully deliver its benefits, the EU and its member states need to have in place a supportive policy environment and compatible regulatory frameworks that would create optimal conditions for quick and efficient development and deployment of 5G. Considering that technological improvements and regulatory policies are often path dependent, one needs to ask whether the EU's longstanding approach vis-a-vis competition rules and regulatory framework is apt for the challenges raised by 5G, and if not, which areas require immediate attention.

In the previous sections we have focused on the status of technological leadership in developing 5G technology and on the gap between the EU's ambition and the actual situation in 5G deployment. With respect to the technological leadership, we have concluded that strategic cooperation through an integrated effort could allow the EU to become a credible competitor vis-a-via the US and China. As for the so far sub-optimal deployment, we have underlined both the gap that separates the EU from its peers and the additional problem of the present lack of information on the effective quality of the deployment.

In any case, the current biggest barrier in this respect seems to be of economic nature and, in particular, it points to a problem of under-investment. According to the European Commission (2020), the sector has an investment gap of €65 billion per year, amounting overall to €250 billion to meet the European Gigabit Society interim targets indicated for 2025. Identified potential causes include the

[8] https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_23_62.

[9] GSMA, The Mobile Economy 2022, available at https://www.gsma.com/mobileeconomy/wp-content/uploads/2022/02/280222-The-Mobile-Economy-2022.pdf.

[10] https://digital-strategy.ec.europa.eu/en/policies/5g.

[11] See, as example, the Research and Innovation Work Programme 2023–2024 (R&I WP2023-24) of the Smart Network and Services (SNS), the institutional partnership between the Commission and the 6G industry in Europe established to fund R&D in this area (https://smart-networks.europa.eu/wp-content/uploads/2022/12/sns_ri_wp_2023-24.pdf) and the results of the flagship project HEXA-X https://hexa-x.eu/about/.

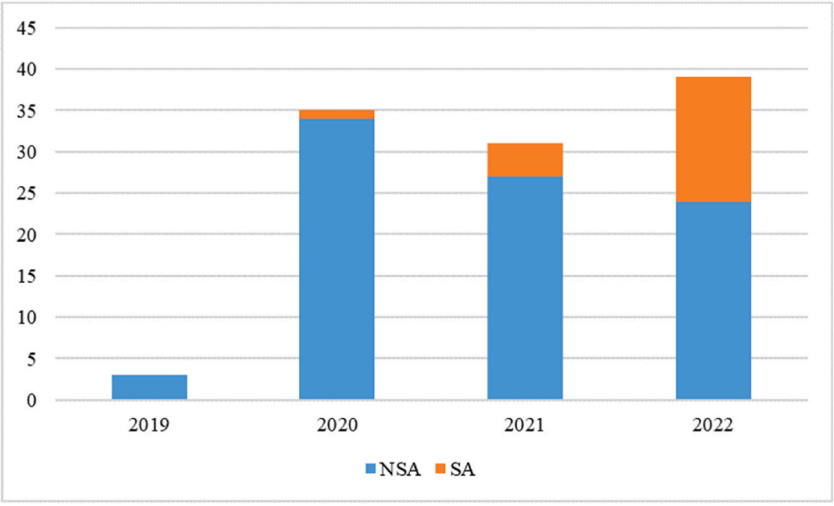

Fig. 1. N° of commercial launches of NSA and SA versions of 5G per year, EU.
Source: our elaboration on 5G Observatory data.

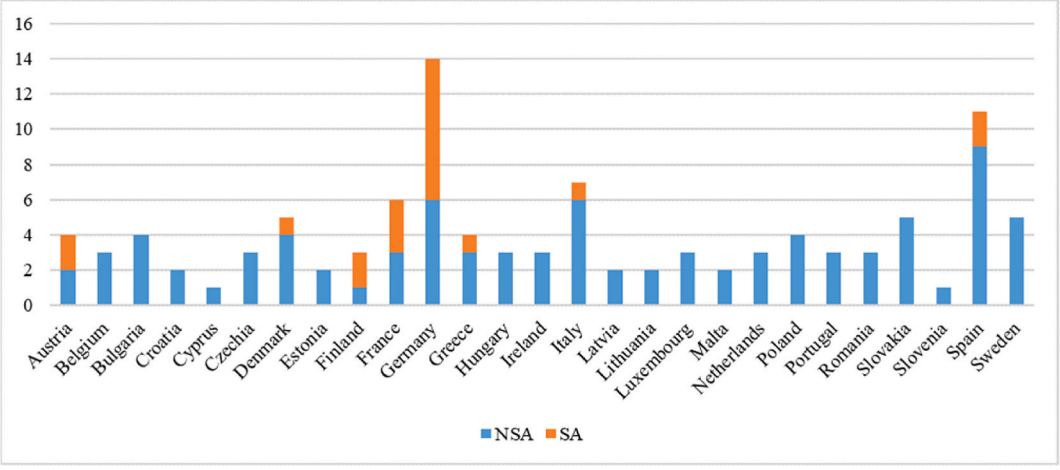

Fig. 2. N° of commercial launches of NSA and SA versions of 5G per country, EU.
Source: our elaboration on 5G Observatory data.

fragmentation of the EU telecom market, intense competition and decreasing revenues In practice, to these contributes a regulatory framework and competition assessment that disproportionately focus on static welfare effects without paying due attention to dynamic effects, the questionable value of stiff net neutrality rules, as well as uncertain business cases for VHCN and 5G. Both under-investment and the EU's lagging position in technological leadership appear to suffer from the similar problem of fragmentation and lack of scale that might exist both at the public policy and company level.

In our view, particular attention should be given to a reinvigorated EU wide industrial policy, and this section discusses whether and how it could help build up the scale necessary to improve the EU's position in technological leadership and overcome the problem of under-investment in deployment of 5G.

In the past, EU "industrial policy" has usually been seen as primarily concerned with improving the functioning of markets and creating horizontal conditions favourable to industrial competitiveness. However, over the years, objectives that influence industrial policy debate have expanded, and today include (i) strategic autonomy, (ii) resilience, and (iii) sustainability (Timmers, 2022). Such expansion is hardly surprising. Technologies are not neutral developments as their perception frames the construction of their reality and identification of challenges and opportunities they represent. With respect to 5G, for example, the question of timing has turned out to be particularly relevant as its initial deployment coincided in time with COVID-19 and the consequential disruption of global value chains and increasing geopolitical tensions. Also, it is the first time, at least in the Internet era, that Chinese companies have taken a kind of lead both in technological development and commercialisation (Erie & Streinz, 2021), gaining increasingly prominent role in the supply of relevant physical components of digital infrastructures that are of critical importance not just for the digital

economy, but also for national security. More generally, this is the first time in the history of telecom networks that security has become a major issue in the purchasing decisions concerning network equipment (Hoffman, Bradshaw & Taylor, 2020). This explains the call for recognising 5G rollout "as a strategic rather than merely a technological choice" (Kaska et al., 2019).

In the world, the countries that are leading in 5G deployment are indeed those where government ambitions, reflected in detailed strategies, have driven deployment before and above consumer demand. For example, the South Korean government prepared a deployment model that has helped the three major telcos to faster deploy the 5G network and to split the deployment costs (Massaro & Kim, 2022). China explicitly supported 'national champions' who could lead 5G to ensure that telecommunications operators would move quickly to stand-alone 5G, in order to enable the widespread use of IoT applications and upgrades in advanced manufacturing (Triolo, 2020). In addition, thanks to the government's focused guidance and investment in technology research and development, Chinese industry has been able to benefit from the economies of scale in its home market, which has effectively been protected from foreign competitors.

In January 2021, the United States adopted the long-awaited government-wide National Strategy to Secure 5G Implementation Plan, which seeks to facilitate the development and deployment of secure and resilient 5G infrastructure. The Plan builds upon the Secure 5G and Beyond Act, which was signed into law by President Trump in March 2020, and which differs from earlier strategies as it lists specific actions that the federal government will take along four identified 'lines of effort', the first of which is to 'Facilitate Domestic 5G Rollout'. This Plan was the result of a growing and bipartisan support for the promotion of an industrial policy regarding the planning of 5G, which reflects the widespread conviction that a successful deployment of 5G, and sustained innovation beyond it, are of national and strategic importance (Brake, 2020).

The key requisites for the effective and rapid deployment of 5G services is spectrum availability and a sound investment environment. In both cases, a highly fragmented structure of the European market contributes to a sub-optimal deployment in the EU. With respect to spectrum, not only the timing of making it available in different bands has varied greatly among the Member States, but also very costly spectrum licensing (particularly in Italy and Germany) has contributed to increasing investment costs, moreover unevenly across the EU. Such a divergence highlights the importance of reaching a consensus at the EU level that long-term benefits to the society should be prioritised over the maximisation of short-term state revenues.

As for investment costs, while they may be increasing also in other sectors, it is important to consider this trend in the specific context of the telecommunications markets. First, national fragmentation creates the need for companies to deal with various regulations across borders, as well as a multitude of application procedures and permits that are needed in order to install 5G equipment, which aggravates the deployment costs. Second, the highly fragmented European telecommunications market is intensely competitive today due to the presence of more than 70 telecom network operators. While such fragmentation has delivered lower prices and interesting retail service innovations to consumers,[12] for EU telecom operators it has resulted in decreased revenues, making it challenging for many of them not only to sustain the growing investment cost that is associated with 5G but also the effort of simultaneous deployment of 5G, 4G and fibre networks. Third, investment in telecoms displays two pertinent special traits: (i) CAPEX that is not just expensive, but also protracted, and (ii) investment in telecom infrastructure, in particular mobile, is cyclical, as it requires regular and rapid upgrades and replacement (Williamson & Howard, 2022). These features are relevant for investors who, operating in increasingly uncertain times (due to high inflation, increasing interest rates and geopolitical tensions), prefer short-term returns and investments that are less sensitive to demand risk. Moreover, when deciding where to invest funds for which they are responsible, investors must take into account many factors, including return on investment (RoI), a dimension where, due to the high cost involved in deploying fibre networks, recently EU telcos have been performing particularly poorly (HSBC, 2021).

It is in this context that one needs to evaluate whether the regulatory model and pro-investment tools foreseen primarily by the European Electronic Communications Code, but also by other accompanying regulations, are fit for purpose. Clearly, telecom operators are strongly concerned that they are unable to close the existing investment gap on their own in a short period of time, and more importantly that despite having invested heavily in both fixed and mobile networks for a sustained period, they are unable to rip the benefits of their investment. These are the concerns that have led to the telcos' request to the big techs companies, operating Over The Top of their networks, to pay a "fair share" of the necessary networks' future deployment and that have fuelled the recently published Commission's public consultation on 'The future of the electronic communications sector and its infrastructure'.[13] While exhaustively exploring the many arguments revolving around this debate falls outside the scope of this article, it is worth noting that the debate itself is not new. However, whereas in the past the EU did not consider OTT to be the cause of the difficulties faced by telecom operators and unapologetically told the operators to 'adapt or die', today its position seems to have swayed.

4.2. A focus on mobile mergers in the EU

The fragmentation of the EU telecom market has long been indicated as a key factor that weakens investment capabilities of EU telecom operators. In that regard, the approach adopted by the Commission in merger control has been criticised for promoting

[12] Lower prices mean that mobile Average Revenue Per User is very much lower in the EU (EUR 14,4) than in the US (EUR 37,9) or in South Korea (EUR 25) (ETNO, 2022).

[13] The consultation has been published on 23 February 2023, and its text can be accessed here: https://digital-strategy.ec.europa.eu/en/consultations/future-electronic-communications-sector-and-its-infrastructure.

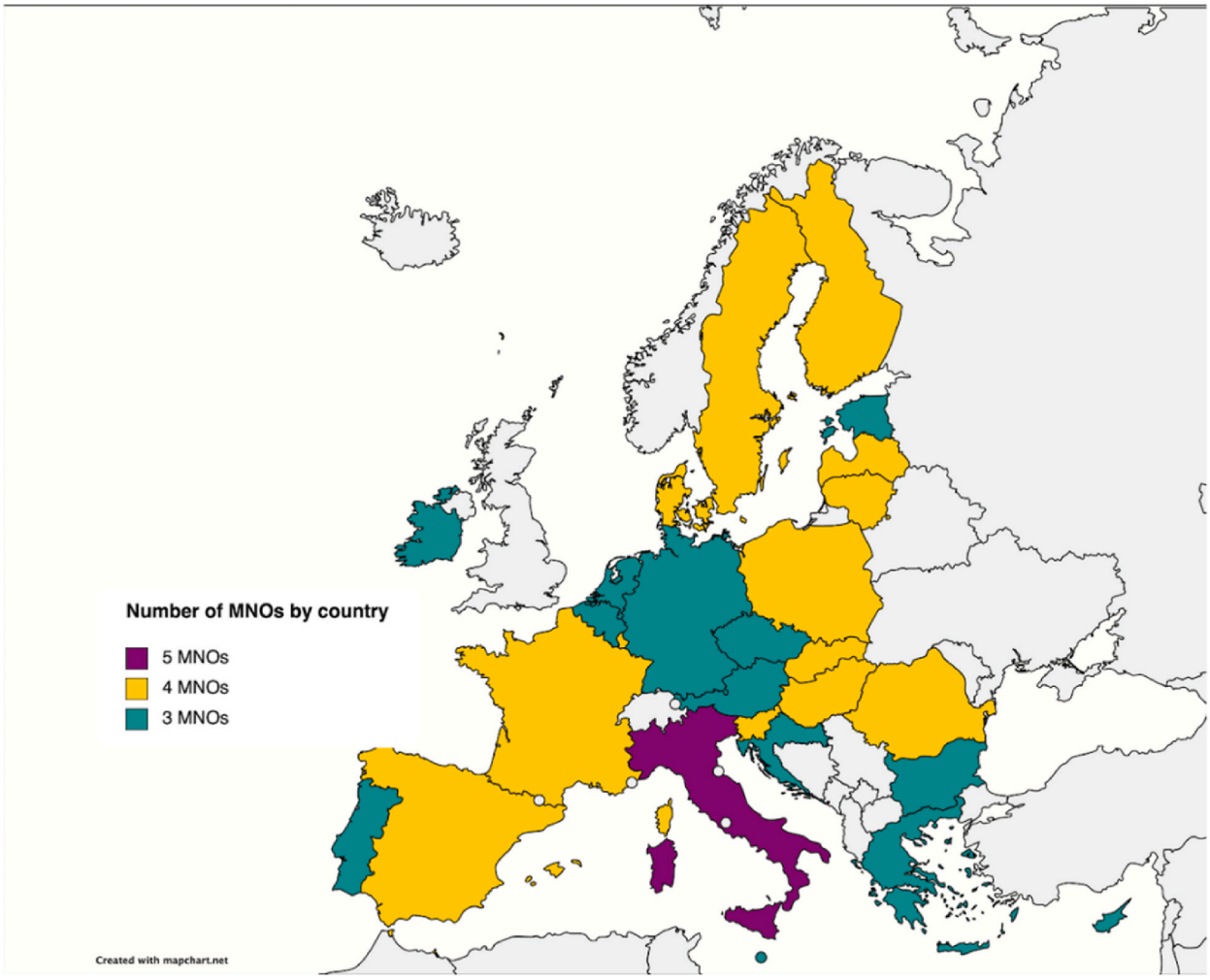

Fig. 3. N° of MNOs by country, EU, 2023
Source: our own elaboration.

artificial competition by implicitly prescribing a specific number of mobile players; preferably four players in each of the national markets.[14] As showed in the map in Fig. 3, today, thirteen EU Member States have three MNOs, thirteen have four, and one, Italy, has five.[15]

As shown in Table 2, since 2007, DG Competition reviewed eight 4 to 3 in-country mobile mergers, approving six of them, mostly with important remedies, and blocking one, while another was withdrawn during the examination.[16] In the last case, parties to a 4-to-3 merger in Denmark have abandoned the transaction as they failed to submit remedies that would fully address competition concerns identified by the Commission.

So far in Europe most mobile mergers in the telecom sector concerned in-country consolidation, which has been subject to a strict scrutiny from the Commission due to concerns about potential anticompetitive effects resulting from the reduction of the number of competing operators. While four-to-three mergers are unlikely to be cleared without an in-depth investigation and most likely also substantial remedies, the recent EU General Court's ruling that annulled the EC's decision to block *H3G/Telefónica* merger is expected to have raised the standard for blocking a merger. Also, both the EU General Court and the US FCC and DoJ acknowledge that while increased concentration may result in increased prices, it can also lead to an increase in network investment and *"facilitate the*

[14] The wave of consolidation in the mobile communications market and the debate about the optimal market structure is not limited to Europe. Australia approved a 4 to 3 merger in 2009, while Chile and Argentina did the same already in 2005.

[15] One could consider H3G Italia/Wind (2016), as a 4-to-4 merger given that with the entry of Iliad (as an essential element of the remedy package) the number of 4 MNOs has remained unchanged. Next, with Fastweb's acquisition of Tiscali's rights to 3.5 GHz spectrum and 26 GHz spectrum during 5G auction, the number of MNOs in Italy has increased to five.

[16] The Commission has also approved two 5 to 4 transactions: *T-Mobile/Tele.ring* (Austria, 2006) and *T-Mobile/Orange* (UK, 2010).

Table 2
Four-to-three mergers between MNOs in the EU (2007–2023).

Merging parties	Investment and deployment related efficiencies claimed by the parties	Outcome and Remedies
T-Mobile/Tele2 NL (the Netherlands, *2018)*	- While it was not necessary to assess efficiency claims as the transaction was deemed not to significantly impede effective competition, the parties claimed that the transaction would, among others, enable an earlier and more extensive rollout of 5G.	Cleared no remedies (Phase II)
H3G Italia/Wind (Italy, *2016)*	- Cost and revenue synergies, - The creation of a third high-quality network as the merger would enable a faster LTE roll out and a higher population coverage than would have been possible absent the transaction.	Cleared with the entry of a new entrant (Phase II)
H3G/Telefónica (UK, 2016)		Blocked
TeliaSonera/Telenor (Denmark, 2015)		Withdrawn
Telefónica DE/E-Plus (Germany, 2014)	· Improved quality: coverage and speed; · Significant (fixed) cost reductions.	Cleared with remedies (Phase II)
H3G UK / Telefónica IE (Ireland, 2014)	· Economies of scale leading to higher investment in network and service quality and more aggressive price competition; · Access to 800 MHz spectrum enabling faster roll out of LTE;	Cleared with remedies (Phase II)
H3GAustria / Orange AT (Austria, 2012)	· Capacity increase of the merged parties' network; · Faster rollout of LTE · Improved network coverage · Reduction of alleged scale disadvantages	Cleared with remedies (Phase II)
T-Mobile/Orange NL (the Netherlands, 2007)	None claimed	Cleared unconditionally (Phase I)

Source: authors' own elaboration.

expeditious deployment of multiple high-quality 5G networks".[17] Given that over half of the EU Member States still have four MNOs, it remains to be seen whether the effects of mergers on the ability of MNOs to invest in network deployment and in the provision of innovative services will play a more prominent role in the merger review process in the future.[18] In its recent ruling in *Commission v CK Telecoms UK*,[19] the Court of Justice overturned the General Court's judgment, which had previously annulled the European Commission's 2016 prohibition decision. While the judgment reaffirms the Commission's discretion in merger control, it remains to be seen how the Commission will use it discretion in future cases. The *Orange/MasMovil* proposed merger in the Spanish telecom market will certainly be a litmus test for understanding whether the Commission is willing to adopt a more lenient approach in that regard. This would certainly require the Commission to consider a more nuanced evaluation of economic evidence, which is very much needed if incentives to invest and innovate are to be properly assessed in mergers today, in particular those that arise in oligopolistic markets.

Another issue concerns the assessment of mergers based on a pan-European market. Cross-border consolidation and creation of pan-European champions, however, have never really come to fruition, which raises the question of whether existing policy are unfavourable to such transactions or whether telecom operators lack incentives to engage in them. The real weight of heterogeneous consumers' behaviour across countries, differences in infrastructure and spectrum allocations (which are particularly relevant in the context of mobile and, especially, in 5G markets), and different tax and labour regulations may all have significantly diminished the potential economies of scale and scope in the EU in that regard.

Today, the EU's position towards cross-border consolidation is openly favourable. At the Mobile World Congress 2023 in Barcelona, EU Commissioner Thierry Breton said that it is time for "a serious discussion about the possible existing obstacles to cross-border consolidation", which seems to be "holding back [EU's] collecting potential compared to other continents" (FT, 2023). Nonetheless, according to Mike Fries, Chief Executive of Liberty Global, cross-border mergers are unlikely to happen as the potential cost savings of being in multiple markets are marginal, and in any case, in-country consolidation must take place first before cross-border mergers become an interesting option.[20] This raises a question about the relevance of sequencing of market consolidation and whether in-country and cross-border mergers are truly mutually exclusive. In any case, more studies are needed to better understand the trade-offs between both types of mergers and the incentives and hurdles that determine whether to pursue one or the other.

Finally, mobile operators might pursue scale and network efficiencies in less radical ways, for instance through the increased use of network sharing agreements. These kinds of agreements might face a less intense competition scrutiny than four-to-three mergers. A further possibility could be represented by mergers involving players operating networks with a different business model. In that regard, an opportunity to test in practice whether the EU is truly more open to cross-border consolidation could soon be tested in the

[17] https://www.justice.gov/opa/pr/justice-department-settles-t-mobile-and-sprint-their-proposed-merger-requiring-package.

[18] Outside the EU, some recent cases seem to suggest that a merger's impact on the ability of MNOs to invest and innovate may indeed gain a more prominent role. See two recent four to three non-EU mergers (T-Mobile/Sprint in the US, and VHA/TPG in Australia), which have dealt with precisely the issue of 5G network investment.

[19] Case 376/20 P, Commission v CK Telecoms UK, ECLI:EU:C:2023:561.

[20] https://www.ft.com/content/ee262b71-4d26-42d9-a25d-6c9b6afc9dfc.

presence of mergers involving a relatively new type of telecom companies: wholesale-only network providers. According to Deloitte (2021), a few major infrastructure players are likely to attempt the consolidation of most of the European telecoms' infrastructure, a move that would allow them to build important economies of scale and scope. One would expect such mergers to raise less competition issues as firms operating on a wholesale-only model would have no incentive to engage in the anticompetitive foreclosures that are typical for traditional vertically integrated telecom operators. Moreover, by separating infrastructural assets from retail consumer-facing operations, pure wholesale network operators could become more attractive to investors. With a typical utility business model, such operators would be more likely to generate steady cash flows over longer periods by leasing their infrastructure to service providers.

If economies of scale and mobile market's attractiveness to investors are decisive for a timely deployment of 5G networks, the fundamental question is whether a change in the approach towards in-country consolidation would suffice or whether a more pro-active policy that would explicitly push for the creation of pan-European mobile market would be needed. Particularly helpful could be policies aimed at stimulating demand for 5G that would lead to more reliable monetization opportunities. For example, committing public authorities to purchase a minimum level of service through anchor tenant agreements would guarantee a minimum level of revenues for MNOs. Also, investment-friendly tax policies, compatible with state aid rules, and policies facilitating cross-sector investment and co-investment in network deployment could help boost demand. However, all such policies should be evaluated at the EU level to avoid the lack of a level playing field among the EU Member States and further fragmentation of the EU telecoms market.

5. Conclusions

In this article, we explored the question of whether the EU needs a more proactive 5G industrial policy, considering that at present it lags quite behind in the global 5G race, both in terms of technological innovation and network deployment. The key question, in this respect is whether the arrival of 5G triggers a different set of opportunities and incentives, both for companies and for public decision-makers.

In the first section of the article, we presented the state of the art of the technological leadership in 5G, reviewing a set of recent studies adopting empirical methodologies based on patents. Following the results of a recent study (Parcu et al., 2022), we observed that the fragmentation of European research and development efforts in 5G limits the potential of the region to compete on equal grounds with other advanced regions of the world. However, the competitiveness of Europe in such a strategic technology could be boosted by a joint effort of the EU and its MS to advance and innovate together in the 5G area, as many of the rare and complex technologies needed are already present in Europe.

In the following section, we described 5G network deployment in the EU. While it is difficult to fully assess the state of deployment across MS in qualitative terms, because of the lack of consistency of procedures and indicators, it is nonetheless clear that the EU is progressing at a slower pace in comparison to other regions of the world.

We have indicated under-investment as one of the key reasons behind the slow progress in 5G deployment. Our analysis has led us to conclude that the same obstacle present in the technological development of 5G may also play a deterrent role in its rapid deployment. Namely, the fragmented nature of the EU telecoms industry seems to act as a disincentive to mobilising the amount of investment that is necessary to ensure that European consumers and citizens can enjoy the rapid deployment of 5G networks.

As a possible remedy, we discuss the need for a careful examination of possible industry agreements and cross-border mergers that would more seriously embody the idea of the single market, even if networks concerned remain primarily national. While the EU's position towards cross-border consolidation is openly favourable, it needs to be seen whether in-country and cross-border mergers are mutually exclusive, or rather, if a certain amount of in-country consolidation must take place first for cross-border mergers to become a viable option. In any case, a hypothetical EU-wide industrial consolidation would not necessarily need to be pursued at the expense of competition on the retail markets and certainly could integrate and benefit from the contribution of innovative EU SMEs along the value chain.

From a public policy perspective, improving the development and adoption of 5G requires the redesign not only of an industrial policy but also a re-examination of innovation policy, spectrum assignments, economic regulation, competition enforcement, as well as of security and resilience-related policies. These are all intertwined issues that today are mostly addressed in separate legal instruments. Given such a complex matrix of policy measures, research on the optimal level at which different policy measures concerning 5G should take place (i.e., national, regional, or EU) would prove particularly helpful for designing a policy environment that could be holistically supportive of 5G development in Europe. It is also clear that an ecosystem or value chain perspective is needed to address the specific challenges of deployment; a position that is evidently reflected in the recently launched consultation on the future of the electronic communications sector (see above), which incorporates the vision that all market actors benefiting from the digital transformation should assume their social responsibilities and make a fair and proportionate contribution to the costs of public goods, services and infrastructures.

In the current political and economic scenario, which, in the aftermath of the COVID-19 pandemic and the war in Ukraine, is clearly more open to industrial policy considerations, and in which – regarding 5G – nearly all the major competitors have engaged in some form of industrial intervention, notwithstanding their different economic choices, this is a conversation that Europe should clearly pursue. It is worth stressing that the discussion about challenges posed by 5G to the EU is clearly relevant also beyond 5G: even if today 6G technology appears still only in its foundational stage the international race for the leadership has already begun. To remain globally relevant and competitive in this race, the EU may need to start treating the development and deployment of 5G, and in the future of 6G, as a true Single Market issue. While in terms of declared policy, the EU's 5G strategy apparently is at the heart of its Digital Single Market Strategy, in practice, the European telecom market continuous to remain excessively fragmented. If we are right in

thinking that the EU underperforms in terms of technological leadership and 5G deployment because of this fragmentation, the situation can be improved only through an adequate policy action to be conceived and deployed at the European scale.

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