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5G is not just another G: A review of the 5G business model and ecosystem challenges

Mattia Magnaghi *, Antonio Ghezzi, Andrea Rangone

Politecnico di Milano, Department of Management, Economics and Industrial Engineering, Via Lambruschini 4B, 20156 Milan, Italy
School of Management, Politecnico di Milano, Via Raffaele Lambruschini 4/b, Milano, 20156, Italy

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ABSTRACT

The fifth generation of mobile communications (5G) is a revolutionary phenomenon, which could deeply change the competitive landscape for wireless services. While 5G is a hot technological topic, there is a dearth of research that specifically explores 5G deployment challenges from a strategic perspective. Such limitation calls for a study, whose aim is to: (i) take stock of the current debate on 5G, (ii) critically review the extant literature with a focus on the theoretical streams employed to investigate the phenomenon from a strategic perspective, (iii) position the 5G research at the intersection of technology and business by identifying and classifying challenges faced by both Mobile Network Operators and other actors in the 5G ecosystem; and (iv) propose relevant future research avenues for theory and practice. To comply with such objectives, we conducted a systematic search and a review on a sample of 23 journal articles concerning the major strategic challenges the 5G ecosystem's stakeholders must face. From a theoretical perspective, we offer a systematic study of the strategic implications of 5G from a holistic viewpoint, without focusing on a specific use case. We analyse the theories currently adopted to investigate the phenomenon, while proposing alternative ones that could generate new research questions. From a practitioner's perspective, our study aims to increase actors' strategic awareness of such technological innovation's implications.

1. Introduction

Throughout its relatively short but lively history, the mobile telecommunications industry has been subject to several dramatic technological shifts, which entailed significant changes in the telcos' business ecosystem (Kuo and Yu, 2006; Funk, 2009; Ghezzi et al., 2015a, 2015b; Oughton et al., 2018). Among such shifts, one which holds the deepest and most crosscutting implications at all levels of the value network is certainly the regulated transition from one generation – or "G" – of mobile network infrastructure to another. From the first generation or 1G deployed in the 80s' to deliver analogue voice services, mobile networks have come a long way and reached their current technological apex with the rollout of 5G, which started in 2019. According to the European Commission, 5G is "*the critical new generation network technology that will enable innovation and support the digital transformation*" (European Commission, 2023). In other terms, 5G is a new and advanced technology with high potential and a broad portfolio of applications it could enable (Cave, 2018; Ahokangas et al., 2021). According to the literature, the shift to 5G networks could be intended as a "game changer" (Knieps and Bauer, 2022), and estimations suggest that focusing on its development in key sectors such as mobility, healthcare, manufacturing, and retail could substantially boost the global GDP, with a potential increase up to $2 trillion by 2030 (McKinsey and Company, 2022).

Despite the enormous potential for growth, both demand and supply-side companies, particularly Mobile Network Operators (MNOs), which have historically played a key role in the volatile telecommunications sector (Du Preez and Pistorius, 2003; Ghezzi et al., 2015a, 2015b), are facing what the literature defines as the digitalisation paradox (Gebauer et al., 2020; Ancillai et al., 2023). This paradox highlights how companies make significant investments in digital technologies, such as 5G, but struggle to achieve the expected outcomes in terms of adoption and revenues.

Furthermore, given the broader applicability of 5G due to its characteristics as an enabling technology (Teece, 2018a), 5G ecosystem is less MNO-centric than what happened for previous generations and other players could take the lead in 5G projects, particularly in defining use cases within specific verticals (e.g., manufacturing, healthcare),

* Corresponding author.
E-mail addresses: mattia.magnaghi@polimi.it (M. Magnaghi), antonio1ghezzi@polimi.it (A. Ghezzi), andrea.rangone@polimi.it (A. Rangone).

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where MNOs currently lack sufficient expertise. This trend is further accentuated in certain countries where MNOs do not have exclusive access to local 5G licenses for private deployments (Bauer and Bohlin, 2022), enabling other actors to operate independently of MNOs.

Therefore, a shift in mindset is required among telecommunications stakeholders to grasp 5G opportunities (Cave, 2018). On the one hand, MNOs must reassess their approaches to value creation, delivery, and capture (Ancillai et al., 2023) to overcome the digitalisation paradox and maintain their central role in the 5G ecosystem. On the other hand, alternative players may seize opportunities to secure new positions. Consequently, the dynamics at both business model and ecosystem levels are now significantly more intricate.

While showing a growth trend in publications and interest of scholars (Mendonça et al., 2022) and although some papers have explored the possible positioning of MNOs with 5G (e.g., Lehr et al., 2021; Gooderham et al., 2022) the current 5G managerial literature presents unstructured and few in-depth references to strategic issues by spanning many topics (e.g., politics and regulations, geopolitical matters, social issues, the COVID-19 pandemic and health-related concerns). There is significant fragmentation that obstructs a thorough understanding of 5G, posing a substantial challenge to the advancement of academic research and practical applications in this field.

Therefore, from both theoretical and practical perspectives, the prevailing approach to exploring the multifaceted 5G phenomenon has been predominantly technology driven. This approach places a strong emphasis on 5G's technical aspects and features, with most of 5G-related publications belonging to the fields of "Electronics and Telecom Engineering" and "Information Technology and Processing" (Mendonça et al., 2022). However, such focus on the technological superiority of 5G compared to other alternatives is currently failing to make a business case for 5G and goes to the detriment of a sound strategic analysis of the business implications of 5G in terms of emerging business models it could catalyse, as well as of the changes in strategic approaches and industry reconfigurations it could call for.

It thus becomes crucial to identify and summarise current 5G challenges also from a strategic perspective, not only in practice, but also to analyse how extant studies have leveraged the strategic management literature as a lens to interpret this phenomenon, as there may be a misalignment between the theory employed and the actual problem.

Therefore, this study aims to: (i) take stock of the current debate on 5G, (ii) critically review the extant literature with a focus on the theoretical streams employed to investigate the phenomenon from a strategic perspective, (iii) position 5G research at the intersection of technology and business by identifying and classifying challenges faced by both Mobile Network Operators and other actors in the 5G ecosystem; and (iv) propose future research avenues with relevance for theory and practice.

The results show that the slow development of the 5G market is reflected in the strategic academic literature related to 5G, where most articles focus on the pragmatism of the issue itself (e.g., in specific fields of application), often at the expense of an adequate theoretical foundation. Moreover, investigations into specific areas or applications tend to involve very stringent boundary conditions for the validity of the results. Most of the reviewed studies emphasise the need for further research, often highlighting as the main limitation the difficulty of applying the obtained results to different contexts (e.g., Gooderham et al., 2022; Henríquez et al., 2022; Kaartemo and Nyström, 2021). This primarily leads to a loss of a holistic view of the problem, favouring a narrow perspective linked to specific cases and lacking a research question anchored to the strategic literature. Indeed, few published works contain in-depth references to strategic issues (e.g., Noh et al., 2021; Henríquez et al., 2022; Moqaddamerad and Tapinos, 2023). The risk, therefore, is that publications on this topic will continue to increase, while remaining fragmented, especially in the theoretical approach taken to analyse the empirical context.

This work contributes to positioning 5G within management literature, summarising the main strategic challenges from the perspective of MNOs' business models, in terms of value creation, delivery, and capture, and the entire ecosystem. We help advance the literature on 5G by proposing several theoretical anchors and possible research questions. These efforts aim to move beyond anecdotal studies, enabling the generation of new findings in the field that may be applicable to broader contexts or to other enabling technologies.

This research also displays practical relevance, due to the strong impact 5G could have on the business model of actors belonging to the mobile telecommunications industry. It seeks to spur companies to develop sustainable business models meant to capture the value that 5G technology promises. Furthermore, the study allows us to contend how the proper market rollout of 5G will bring about the necessity to create an active ecosystem in the telecommunication industry and beyond; an ecosystem within which traditional actors may need to revisit their resources endowment, strategic positioning, and mutual relations.

2. Research background

2.1. 5G is not just another G

The fifth generation of communications technology (5G) is expected to cover and satisfy the unmet needs in different application fields with its intrinsic characteristics that can be summarised into the following features: (i) enhanced mobile broadband, (ii) ultra-reliable and low-latency communication, and (iii) massive machine-type communications (ITU-R, 2015; Matinmikko et al., 2018). Due to its pervasiveness, 5G is envisioned to become the foundation for future services. It has almost infinite applicability, which may change the development trajectory of the telecommunication industry and beyond (Gooderham et al., 2022). Due to these characteristics, several authors classify it as an "enabling technology" or "Junior General-purpose technology" (Teece, 2018a, 2018b; Schneir et al., 2019; Rathje and Katila, 2021). Enabling technologies are upgradable, adaptable technologies with improvement potential for broad applicability (Gambardella et al., 2021). Though they share part of the General-purpose technology (GPT) definition (Bresnahan and Trajtenberg, 1995), namely the potential for continuous technical enhancement and the enablement of additional innovations in various application sectors, their economic impact in terms of pervasive and extensive use is still uncertain (Teece, 2018a).

The technical literature on 5G appears to be more well-established than the managerial one, and this is not surprising, given that 5G is a cutting-edge technology that has required years of research. This aspect is clearly stated in the bibliometric analysis conducted by Mendonça et al. (2022), where most of the publications included belong to "Electronics and Telecom Engineering" and "Information Technology and Processing". However, it is rather surprising that only 0.23 % of the publications belong to the "Business and Economics" category, considering that the first release (Release 15) was issued in 2018. Indeed, from a technological perspective, it seems that 5G has reached an appropriate level of development.

2.2. The fragmented 5G managerial literature

Conversely to the technical one, 5G management literature appears to be very fragmented and spans numerous topics. These include politics and regulations (e.g., Tang, 2020; Kuś and Massaro, 2022; Buggenhagen and Blind, 2022; Nikolic and Galli, 2022), geopolitical matters (e.g., Friis and Lysne, 2021), development towards 6G (e.g., Pei et al., 2023; Kim and Park, 2022) social issues (e.g., Naserian et al., 2021), the COVID-19 pandemic (e.g., Erokhin et al., 2022), and health-related concerns (e.g., Hardell and Carlberg, 2021). Concerning the last two, undoubtedly, the fact that this technology emerged during a historical period such as the COVID-19 pandemic and subsequent ongoing conflicts has led to it being interwoven into technological discussions with many other issues.

Moreover, there is, justifiably, a strong focus on the 5G infrastructure deployment, which acts as a catalysts for the development of 5G. Scholars (e.g., Bauer and Bohlin, 2022; Teece, 2021; Blind and Niebel, 2022) underscore the fact that the 5G network infrastructure requires significant investment in physical layers, with one major bottleneck in 5G deployment being the scarcity of physical assets. The high risks associated with the rollout, particularly the uncertainty of adequate returns, constrain investments. Teece (2021) identified three technological layers related to 5G deployment: the first layer includes infrastructure (e.g., equipment), components (e.g., chips), and devices (e.g., phones and tablets).

Together with the physical infrastructural layer, 5G technology has introduced governance and regulatory challenges never seen before (Knieps and Bauer, 2022). This is particularly true concerning the deployment of local 5G networks, which constitute one of the main themes when referring to the development of applications in the vertical industrial context (Vuojala et al., 2020). 5G allows the development of deployments on a wider spectrum range, from 450 MHz to 24.25–52.6 GHz (Bauer and Bohlin, 2022). In some countries, such as South Korea, new access conditions for private network providers have been defined. In particular, the Korean government reserved 600 MHz in the 28 GHz for private network providers other than MNOs. This resembles what is happening in some European countries such as Germany, France and Finland, where private companies have the possibility of accessing local licenses to build their own 5G networks without involving MNOs for spectrum access.

Therefore, existing literature clearly reveals that the telecommunications industry is highly regulated, with regulators' actions in such ecosystems having a significant impact on corporate performance in terms of investment and innovation (Bauer and Bohlin, 2022).

However, as mentioned, it is not solely a regulatory matter. Indeed, companies must also tackle other business challenges to fully capitalise on the opportunities that 5G promises, given its nature as an enabling technology (Teece, 2018a, 2018b). This is especially relevant for MNOs, the traditional incumbents in the industry, whose strategic positions could either be greatly strengthened or considerably weakened depending on the trajectory of 5G's evolution. Nevertheless, the majority of existing studies are specific in terms of empirical context investigated and focus on specific applications or application fields. The most recurring ones are manufacturing and operations (Dolgui and Ivanov, 2022; Knieps and Bauer, 2022), urban areas (Rendon Schneir et al., 2019), logistics (Rendon Schneir et al., 2022) and healthcare (Kaartemo and Nyström, 2021). In these cases, the papers illustrate the potential of 5G in various fields without explicitly mentioning the challenges and strategic choices of the players involved. For instance, the fact that MNOs are going through a period of crisis and change is recurrent, and some authors have summarised the stages of their evolution in terms of strategic positioning (e.g., Gooderham et al., 2022), while others have reported on the evolution of mobile technologies (Forge and Vu, 2020). However, the strategic implications stemming from the adoption of 5G struggle to come to the forefront. Instead, considerations are made about possible technological developments or changes concerning spectrum choices or infrastructural considerations (e.g., Forge and Vu, 2020; Knieps and Bauer, 2022).

Moreover, published works contain unstructured and few in-depth theoretical references to the strategic issues and, in particular, to the implications on business models enabled by 5G, without giving a comprehensive overview. Indeed, from a theoretical standpoint, it is unclear how the strategic literature is being leveraged to interpret the phenomenon. Hence, there could be a misalignment between the theory employed and the actual challenges. What is lacking is comprehensive work that allows for holistic observation and assessment of the strategic challenges deriving from the adoption of 5G.

In light of these considerations, our study aims to position the theme of 5G in the managerial literature. It attempts to recap the current challenges for Mobile Network Operators and all the players joining the 5G ecosystem, as well as to review current theoretical foundations used to investigate the phenomenon from a strategic perspective, finally proposing relevant future research avenues for both theory and practice.

3. Methodology

In this section, we outline the approach used to review 5G strategic literature. To make every choice and every step transparent, we considered the systematic review principles of the identification phase for the development of a review protocol proposed by Tranfeld et al., 2003. By doing so, the research aims to be unbiased, falsifiable, reproducible, and scalable over time.

3.1. Review criteria

Once the research scope has been clarified, we delved into 5G managerial literature to identify and select relevant research to be included in our review by defining inclusion and exclusion criteria (Higgins and Green, 2011). Specifically, it is possible to maximise sensitivity through them by minimising the risk of excluding relevant papers, and to maximise specificity by excluding papers which are not. However, it is essential to find the right balance between them. Hence, this research maximises sensitivity to a reasonable extent by selecting keywords to first broaden the field of the research, and then to narrow it down with the abstract and text screening process by applying more restrictive exclusion criteria.

3.1.1. Inclusion criteria

The choice of keywords has been determined by terms commonly used to describe 5G in both academic literature and practitioner contexts. Certainly, the acronym "5G" is the most widespread and no other forms would need to be entered into the query for inclusiveness (Mendonça et al., 2022); however, in our case, some of the most recurrent extended forms have also been included, such as "Fifth generation of mobile communication technology", accompanied by variations such as "mobile network" or "wireless network". The authors decided not to include the words "strategy" or "business model" or "strategic adoption" to be as inclusive as possible, and to avoid restricting the research to the strategic perspective from the outset. Hence, they did not exclude any study that may not have explicitly mentioned this perspective but nevertheless discussed it and had to be included.

Other inclusion criteria regard the domain of the papers selected, which is Business, Management and Accounting. Furthermore, the subject areas of Social and Decision Sciences have also been considered to broaden the analysis. Finally, only articles and reviews in English were considered due to their higher quality (Table 1).

As in other reviews (e.g., Ghezzi et al., 2018), keywords and inclusion criteria were applied to the SciVerse Scopus database. Scopus database was selected as it is largely recognised as being significantly comprehensive (including over 90 million records from 7000 publishers,

Table 1
Construction of the search query.

Elements	Translation into query
5G; Fifth generation technology; Fifth generation of mobile communication, Fifth generation of wireless network; Fifth generation of mobile network	TITLE-ABS-KEY ("5G" OR ("fifth generation" W/7 (("technolog*") OR ("mobile communication") OR ("wireless network") OR ("mobile network"))
Area & Type	AND (LIMIT-TO (SUBJAREA, "DECI") OR LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJECTAREA, "BUSI")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTTYPE, "re"))
English Content	AND (LIMIT-TO (LANGUAGE, "English))

as of October 2023), when compared to, for instance, Web of Science.

The initial output from the search process on the SciVerse Scopus database based on the above query was 1222 papers, updated in May 2023.

3.1.2. Exclusion criteria

Through abstract screening, the initial search output was hence subjected to the application of the following exclusion criteria.

1) Studies with a clear focus on technicalities (221 records): several papers delve into applications enabled by 5G ultra-low latencies, higher reliability and rated data. In these cases, the focus is on technical improvement, which leads to extra performance in several fields (e.g., Nyangaresi and Rodrigues, 2022). The reason these works are not included in the conceptual review is due to the absence of a clear connection with the objective of our study.

2) Studies where 5G is not the core theme (109 records): all the works where 5G is merely mentioned such as an enabler for other applications discussed in the abstract have been excluded. In general, recurring themes include the Internet of Things (IoT) (e.g., Rejeb et al., 2023), as well as other technologies like Blockchain (Saraswat et al., 2022), Cloud computing (Iranpak et al., 2021), and Artificial Intelligence (AI) (Balmer et al., 2020). The focus of these works is the shift from 5G to these applications, and most of them require specific expertise in the mentioned sectors or technologies. Furthermore, studies that focus on 5G Advanced (e.g., Lin, 2022) or delve deeper into the realm of 6G (e.g., Adhikari and Hazra, 2022) have also been excluded.

3) Clear focus on geopolitical (38 records), standard and spectrum management (16 records), sustainability (14 records), social issues (15 records) and COVID-19 (28 records): numerous articles examine political dynamics, such as the ongoing technological race between China and the United States, while others concentrate on analyses intricately linked to specific countries under scrutiny. Additionally, as stated earlier, articles addressing spectrum management have been omitted since they concern the political choices of the various states, and specialised knowledge is required for proper understanding. Moreover, the topic of 5G is sometimes discussed in a contentious way, encompassing health concerns, conspiracy theories, and social acceptance. Consequently, articles discussing 5G in relation to health (e.g., Hardell and Carlberg, 2021), COVID-19 (e.g., Erokhin et al., 2022) and specific social issues (e.g., Naserian et al., 2021) have been excluded, thus aligning the research objective with strategic and entrepreneurial aspects. Any article diverging from this thematic scope has been excluded unless unequivocal implications for the field are inherently implied. Moreover, studies involving sustainability implications (e.g., de Oliveira et al., 2023; Williams and Bergman, 2023) have been omitted, as these crucial subjects warrant a distinct literature review.

4) SCImago Journal Ranking (737 records): to guarantee the quality of the journal outlet considered and the soundness of the business considerations put forward, as proposed in extant published reviews.

(Huynh et al., 2023; Hasanah et al., 2023), only articles published in journals listed in SCImago Journal ranking and with a given threshold (Q1 quartile) have been included (García et al., 2011). Of the journals included, to ensure the quality of the works, we verified that they were included in the ABS Ranking to ensure they were not published in a predatory journal.

The application of the exclusion criteria led to the identification of a sample of 44 articles, which were then subject to full-text screening. Such screening revealed that 21 records were out of the scope of our study and could, therefore, be discarded.

3.2. Data analysis

The documents resulting after full-text screening and included in the final sample are 23 (See Fig. 1). The sources of the studies considered are reported in Table 2.

The articles collected have been examined through a comprehensive research protocol (or "data extraction form" for meta-analysis – Higgins and Green, 2011), which considered both descriptive and content

Table 2
Sources of the articles included.

Source	Number of studies included
Telecommunications Policy	11
Technological Forecasting and Social Change	4
International Journal of Production Research	1
Journal of International Management	1
Research in Transportation Business and Management	1
Journal of Business Research	1
R and D Management	1
Journal of Innovation and Entrepreneurship	1
Strategy Science	1
California Management Review	1

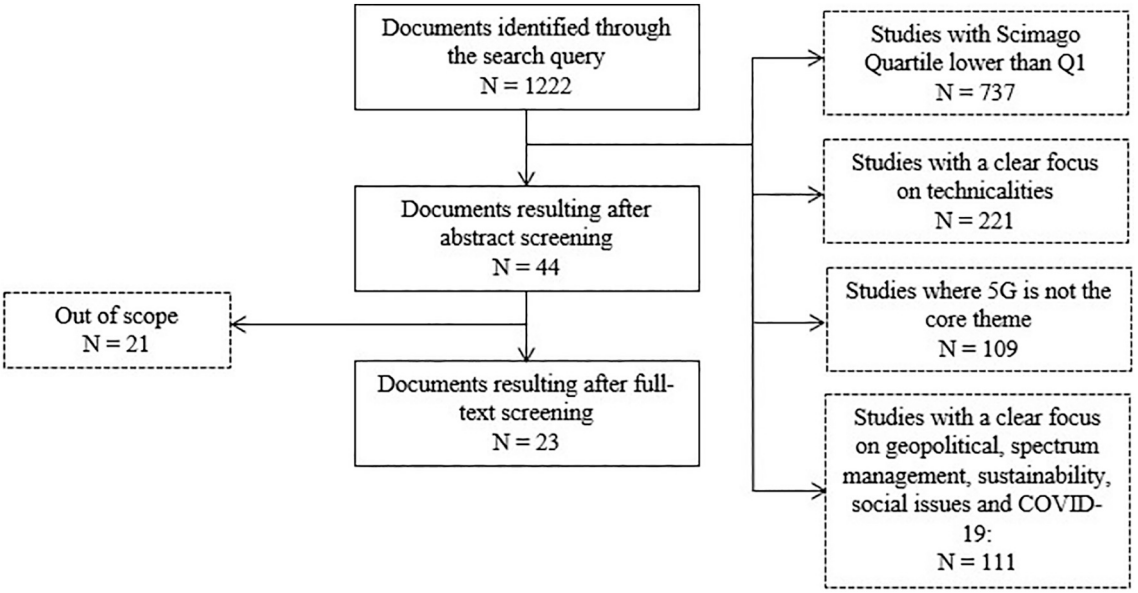

Fig. 1. The screening process.

Table 3
Definitions of 5G-enabled managerial reconfigurations.

Authors	5G definitions in the managerial domain
Ahokangas et al.,2021	*"5G network itself has been understood as a connectivity platform"*
Bauer and Bohlin, 2022	*"5G networks are unified, enabling platforms that support a broad range of use cases"*
Blind and Niebel, 2022	*"5G refers to the 5th generation of network technologies where each 5G 'Release' by the 3rd Generation Partnership Project (3GPP) covers new use cases"*
Cave, 2018	*"5G […] new and very powerful form of mobile connectivity"*
Dolgui and Ivanov, 2022	*"5G technology is an instigator and enabler of end-to-end connectivity between organisations, processes and devices"*
Gooderham et al., 2022	*"5G […] an emerging global digital infrastructure"*
Henríquez et al., 2022	–
Kaartemo and Nyström, 2021	*"5G […] an emerging technology"*
Knieps and Bauer, 2022	*"5G […] General-purpose technology (GPT)"*
Lee and Yu, 2022	*"5G is the fifth generation of mobile technologies"*
Lehr et al., 2021	*"5G represents a paradigm shift. It is more of a toolbox of capabilities than a one-size-fits-all technology"*
Lemstra, 2018	*"5G […] ubiquitous and high-capacity electronic communication infrastructure […] cornerstone of economic development and productivity growth"*
Massaro and Kim, 2022	–
Matinmikko et al., 2018	*"5G […] new generation of wireless network technologies known which can revolutionise the traditional mobile communication business ecosystem by connecting billions of devices and ultimately digitising the entire society"*
Moqaddamerad and Tapinos, 2023	*"5G […] intelligent technology"*
Noh et al., 2021	–
Olokundun et al., 2022	*"5G is essentially an upgrade to the more popular 4G (fourth generation of broadband data-networking digital communications technology)"*
Oughton et al., 2018	*"5G is not just a technological connection but will affect different socio-economic sectors and will stimulate innovation in small companies"*
Rathje and Katila, 2021	–
Rendon Schneir et al., 2019	*"5G […] promising technology that has the potential of enabling several attractive services over time"*
Rendon Schneir et al., 2022	*"5G […] technology that was designed to provide citizens with access to faster and innovative wireless services"*
Savunen et al., 2023	–
Teece, 2021	*"5G […] new paradigm in mobile connectivity designed to connect everyone to everything anywhere. Enabling this development is fifth-generation wireless technology (5G)"*

information. Concerning the former, the title, year, author/s, publication outlet, article type, have been mapped. Concerning the content information, we first classified the articles by research method and theoretical lens used (if present). By doing so, we were able to identify the boundary conditions of studies in terms of scope of validity (if present). Moreover, four categories were defined to analyse the main findings: Definitions, Applications enabled, MNOs' challenges, and Ecosystem's challenges. The first two categories focus on how 5G has been defined from a managerial perspective and what the main application areas are. For these, we considered both the applications mentioned in the text and the empirical context (e.g., when 5G was used as an empirical field to investigate a research question). The third category includes all information related to MNOs, as they are the focal players in the mobile telecommunications industry, and 5G is a key strategic topic for them. The final category concerns the 5G ecosystem, incorporating all information related to how 5G enables the presence of new players, as the industry is no longer solely telco-centric, especially considering the multiple industrial applications.

4. Results: 5G definitions, application enabled and boundary conditions of studies

4.1. 5G definitions in the managerial domain

5G differs from earlier generations of cellular standards in several key respects: (i) it is a very new technology with high potential and a broad portfolio of applications (Cave, 2018; Ahokangas et al., 2021); (ii) it may change the development trajectory of the basic business model for mobile network operators (MNOs) (Oughton et al., 2018; Lehr et al., 2021; Gooderham et al., 2022); and (iii) due to the multiple usages and industrial-use cases, it entails a wider network community (Bauer and Bohlin, 2022; Blind and Niebel, 2022).

In the studies analysed, scholars attempt to apply "the technological definition" in the managerial domain, thus emphasising 5G's "managerial reconfiguration" potential. Due to its pervasiveness, improved technical features', and the fact that it enables many applications in different sectors, several authors use the definition of General-purpose technology (GPT) (Bresnahan and Trajtenberg, 1995) to describe 5G. Knieps and Bauer (2022) use the GPT concept mentioned from a network economic perspective by emphasising once again the diverse range of smart applications 5G can enable. Teece, 2018a, 2018b, p.1369) downsizes this definition by describing 5G as a "junior general-purpose technology": although he considers 5G a disruptive and promising technology in several industries, since its "economy-wide impact" has not been measured yet, he classifies it as an "enabling technology", which is exactly a "junior version" of the Bresnahan and Trajtenberg's definition of GPT (1995).

Given the number of application areas in which it can have an impact and due to the number of stakeholders that could be involved, Lehr et al. (2021, p.1) describe 5G as "a toolbox of capabilities" rather than a "'one-size-fits-all technology". The authors refer to 5G also as a "paradigm shift", and such interpretation is recurrent in other works where 5G is considered a milestone for mobile networks operators, since it includes all the technical features presented by previous technologies in the IT industry (Gooderham et al., 2022). In this sense, the shift to 5G networks could be intended as a "game changer" (Knieps and Bauer, 2022), especially by considering the large variety of local, 5G-based and IoT applications it can enable in several vertical industries (Knieps and Bauer, 2022).

This initial overview of its definitions confirms that 5G is receiving management attention, given its cross-sectoral impact in multiple sectors and the large number of applications it can enable. It is expected to support radical industrial transformations, which not only will have an impact on the levels of connectivity such as higher data rates, traffic density, reliability, and lower latency (Cave, 2018; Massaro and Kim, 2022), but it will also shape the socio-economic sectors (Olokundun et al., 2022). Therefore, such a technological paradigm shift will change the rules of the game in the mobile marketplace (Cave, 2018), which has become a very competitive high-tech-based industry, with several new players entering it.

Table 3 reports 5G definitions implying the technology's potential for managerial reconfiguration.

4.2. Applications enabled by 5G

Lee and Yu (2022) summarised other reasons which justify why 5G differs from its predecessors in three ways: (i) the possibility of connecting everything through networked products and services and not only through people; (ii) the promise of guaranteeing massive, high-capacity, high-reliability and low-latency connectivity to support a variety of scenarios; and (iii) the "scenario-based" slicing. Massaro and Kim (2022) agreed in differentiating 5G from previous generations, mentioning the higher data rates, traffic density, reliability, user speed, lower latency, connectivity for a great number of devices, and lower power enabling Internet of Things (IoT) applications. As mentioned so far, the majority of the 5G managerial reconfiguration presented refers to the possibility of enabling several enterprises' applications across many sectors (Knieps and Bauer, 2022). According to Bauer and Bohlin (2022), the 5G technology is mostly targeting the managerial and industrial market rather than the mass consumer market that has been the traditional market until now for MNOs.

Ahokangas et al. (2021) summarise the five areas where 5G is expected to radically change future wireless networks. The first area mentioned regards densification and improved capacity through millimetre-wave cells, and the second one is localisation through the distribution of radio and core functions, content and services on edge clouds to pursue low latency, high reliability, security, and privacy. The third and the fourth areas regard, respectively, the decomposition of network functions to increase flexibility and scalability to achieve a higher level of automatisation in management and orchestrator. Finally, the fifth area is related to network virtualisation, especially network slicing, to enable "new as-a-service business models". Furthermore, Lehr and colleagues (2022) put forward similar market opportunities in three macro categories, namely: (i) enhanced Mobile Broadband; (ii) wide area coverage for niche applications; and (iii) local coverage.

As emerged from the studies reviewed, 5G plays a crucial role in providing and transferring data. This is essential to enable applications such as cloud manufacturing, digital twins and data-driven modelling (Dolgui and Ivanov, 2022). These solutions, based on real-time data sharing, will bring benefits to logistics, product manufacturing and warehouse management automation, and they will be a crucial part of the future digital supply chain (Dolgui and Ivanov, 2022). In these applications, the deployment of local and private 5G networks is a tangible opportunity for both MNOs and new stakeholders, according to the regulations in the different sectors (Ahokangas et al., 2021). Many industrial companies are seeing in the 5G transition the possibility of digitising themselves (Ahokangas et al., 2021), especially small and medium enterprises that have the opportunity to deploy such a transition to stimulate innovation (Olokundun et al., 2022). Accordingly, Knieps and Bauer (2022, p.3) defined local industrial networks as "*natural experiments of a competitive search process toward innovative solutions*". In this sense, all the 5G-enabled local and dedicated networks such as smart manufacturing, smart agriculture, augmented maintenance, and safety monitoring must become a point of attention for every entrepreneur and company, since they would be able to satisfy heterogeneous needs under certain conditions (Knieps and Bauer, 2022). In the same vein, Vuojala and colleagues (2020) underline an important aspect regarding such opportunities, that is, 5G applications are no longer strictly connected to the mobile broadband services traditionally provided by mobile network operators; rather, they refer to many service categories, especially in vertical industries, such as manufacturing, transportation, energy, media and entertainment, and healthcare. A similar perspective is adopted from Lehr and colleagues (2022) since they explicitly underscore the fact that 5G is less "MNO-centric" than previous technologies since it has engaged many stakeholders, especially if the possibility of deploying private, standalone 5G networks is considered, as previously mentioned.

By examining the empirical contexts in which the papers covered in this review attempt to analyse the implications of 5G, the prevailing applications field is the port (Ahokangas et al., 2021; Henríquez et al., 2022; Rendon Schneir et al., 2022). Kaartemo and Nystrom then analyse the impact of the emerging technology platform in healthcare, while the empirical setting of Moqaddamerad and Tapinos (2023) concerns smart grid. What emerges is that, even if some recurrent application fields are present (e.g., ports), there is still some uncertainty concerning a 5G business case (Blind and Niebel, 2022). The mechanism of value creation from its adoption in different applications is still unclear (Dolgui and Ivanov, 2022), especially considering that other alternative technologies such as Long Range Wide Area Network (LoRaWAN) or Wi-Fi may satisfy the same needs at lower costs (Blind and Niebel, 2022). According to Massaro and Kim (2022), the lack of killer services or a killer application refers to both the B2C (business-to-consumer) and the B2B (business-to-business) sectors, and many solutions are still in R&D (Knieps and Bauer, 2022); therefore, only once it will be clear how to generate value from the adoption of 5G will it be possible to scale the technology up across different sectors (Dolgui and Ivanov, 2022).

4.3. The boundary conditions of 5G studies

Given the 5G-enabled applications described in the previous section, the reviewed papers appear to suffer from a localisation of results in specific empirical contexts. They often cannot be easily generalised. Therefore, in this section, before delving into the strategic challenges identified, we address the scope and idiosyncrasies of the papers: specifically, Table 4 below provides a summary concerning the generalisability of these studies with respect to their scope of analysis and methodology.

In the sample of papers considered, most are conceptual pieces (11) delving into specific aspects of the topic. For these works, no distinct boundary conditions, namely, the scope of validity of the study, were identified, as they address the topic in a descriptive manner, often utilising data from secondary sources.

Most of these papers regard issues of regulations or policy (e.g., Bauer and Bohlin, 2022; Blind and Niebel, 2022; Knieps and Bauer, 2022), especially concerning the deployment of local 5G networks, which has introduced governance and regulatory challenges never seen before (Knieps and Bauer, 2022), as already mentioned.

Other conceptual papers take a more strategic approach by focusing on considerations related to the technological adoption of 5G and its impact on user firms across various sectors (e.g., Dolgui and Ivanov, 2022) or by typology (e.g., Olokundun et al., 2022), or by comparing 5G with previous connectivity technologies (e.g., Cave, 2018; Lehr et al., 2021).

Concerning the remaining papers, as shown in Table 4, most are qualitative analyses based on exploratory single case studies (6). In addition to being relatively limited in number, their findings often lack generalisability because they prioritise the practical aspects of the problem over theoretical considerations. Furthermore, the boundary conditions primarily pertain to context-specific (e.g., Noh et al., 2021) or region-specific (e.g., Lee and Yu, 2022) factors, which makes replicating

Table 4
Boundary conditions of the studies.

Authors	Research objective	Methodology	Field of investigation	Boundary condition
Ahokangas et al.,2021	Identification of 5G connectivity and data platform configurations in industrial multi-stakeholder platform ecosystems of private 5G network: typology, management actions and regulatory challenges	Single future-oriented case study	Finnish 5G-Viima research project: Port of Oulu	Context-related (The dynamics and needs of a port can be different from other industrial sectors or from other types of multi-stakeholder ecosystems. Moreover, the variability of regulations between countries to develop local 5G network makes it difficult to generalise the results to other regions or markets)
Bauer and Bohlin, 2022	Identification of the desired and potential undesired effects of 5G policy on investment and innovation	Conceptual paper	Europe and North America	–
Blind and Niebel, 2022	Identification of market, system, and transformational systems failures related to the roll-out of 5G as system innovation and their respective innovation policy measures	Conceptual paper	Europe	–
Cave, 2018	Shedding light on the disruptive impact of 5G	Conceptual paper	–	–
Dolgui and Ivanov, 2022	Identification of theoretical underpinning and structured conceptualisation of application areas and the role of 5G in future transformations of value creation in digital supply chain	Conceptual paper	–	–
Gooderham et al., 2022	Identification of the firm-specific advantages MNOs need to develop in order to become more than a provider of best-effort internet connectivity as they enter the 5G era	Single case study	Strategic positioning of Telenor	Context-related (it provides in-depth insights specific to Telenor's strategic decisions and market conditions but lacks broader empirical data that could be generalised across the entire MNO industry. Moreover, combining and shaping FSARs identified into a viable business model remains uncertain)
Henríquez et al., 2022	Investigation of business model innovation driven by Industry 4.0 technologies in a seaport context	Exploratory case study	Port of Barcelona	Context-related (the dynamics and needs of a port can be different from other industrial sectors or from other types of multi-stakeholder ecosystems. Little theoretical 'anchorage')
Kaartemo and Nyström, 2021	Exploring how an emerging technology may act as a platform for market shaping and innovation	Delphi study	Healthcare market	Context and region-specific (the healthcare sector is a highly regulated industry, and regulations vary from country to country. Moreover, the healthcare market is more heavily impacted by technology that enables reliable flow of data for various remote services and monitoring)
Knieps and Bauer, 2022	Examination of public policy and management dimensions related to the effective governance of 5G innovation	Conceptual paper	–	–
Lee and Yu, 2022	Explanation of the transition processes across the niche, national and global levels of 5G transition	Single Case study	China technological transition towards 5G	Region-specific (the characteristics of the region are specific, and the interaction between the various identified layers is still something to be discovered and may perhaps depend on the region itself)
Lehr et al., 2021	Comparison of 5G with earlier generations of cellular and related wireless technologies and examination of the economic forces changes with 5G	Conceptual paper	–	–
Lemstra, 2018	Identification of commonalities and differences between successive generations of mobile technology, their introduction and the market adoption that followed	Conceptual paper	Leadership role in 2G-GSM, 3G,4G in Europe	–
Massaro and Kim, 2022	Identification of components responsible for the development of the 5G socio-technical system and those not sufficiently developed impeding further growth of the system	Conceptual paper	South Korean ICT industry and three main Korean MNOs	–
Matinmikko et al., 2018	Development of a tutorial overview on how 5G innovations impact mobile communications, and review of the regulatory elements relevant to 5G development for locally deployed networks.	Conceptual paper	–	–
Moqaddamerad and Tapinos, 2023	Investigation regarding uncertainties' management during the development of new business models	Explanatory single case study	A specialised supplier of power, communication, smart grids, and fibre	Context-related (one organization in a specific geographical region. Results should be verified for different actors)
Noh et al., 2021	Proposing a new technology-driven roadmapping approach that can strengthen the forecasting function of road mapping and the analysis of relationships between business and technology opportunities.	Mixed approach	United States Patent and Trademark Office (USPTO)	–
Olokundun et al., 2022	Development of a theoretical framework to predict relationships between the	Conceptual review	–	–

(*continued on next page*)

Table 4 (*continued*)

Authors	Research objective	Methodology	Field of investigation	Boundary condition
	implementation of 5G technology and digital innovation in SMEs			
Oughton et al., 2018	Quantification of the uncertainty associated with the future demand for mobile telecommunications infrastructure, to test how different strategies perform over the long term.	Cambridge Communications Assessment Model testing	Britain	–
Rathje and Katila, 2021	Investigation on how inventions developed by private firms in collaboration with public sector partners differ in their enabling technology trajectory compared to those developed without such partnerships.	Machine learning	Public-private relationships and comparable private-firm only efforts from 1982 to 2002.	–
Rendon Schneir et al., 2019	Analysis of the impact of different elements driving the business case of a 5G network	Techno-economic analysis	3 boroughs of central London, UK, for the period 2020–203	Context-related (there are several assumptions for the cost analysis, pertaining to the central London area. Other areas might have different cost drivers, which could result in higher costs)
Rendon Schneir et al., 2022	Analysis of the impact of different elements driving the business case of a 5G network	Techno-economic analysis	Hamburg port	Context-related (other ports or other areas where 5G services could be provided will have different characteristics)
Savunen et al., 2023	Providing a review of ongoing public safety mobile broadband projects in which mobile operators play a key role.	Inductive case study	Public safety mobile broadband projects	Context-related (the business model presented pertains to a specific case, namely the public safety market)
Teece, 2021	Shedding light on technological leadership and 5G Patent Portfolios	Conceptual paper	–	–

the results challenging. For instance, the approach taken by Ahokangas and colleagues (2022) to map the actors of the Port of Oulu from a platformisation perspective can be reproposed for other private 5G network cases; however, the results are very specific and case-related, leaving the ecosystem dynamics that lead to the creation of those roles somewhat anecdotal.

The studies by Gooderham et al. (2022) and Moqaddamerad and Tapinos (2023) are single case studies focused on specific actors (an international MNO in the first case, and a specialised supplier of power, communication, smart grids, and fibre in the second one). Hence, their findings are difficult to generalise as well. Nevertheless, in the latter study, 5G is used as an empirical field to address a research question that fills a gap in the literature on business model innovation, making the findings potentially verifiable in other contexts. Only a few papers (3) examine 5G as an empirical field to explore a research question arising from a theoretical gap. Consequently, the literature on 5G is quite fragmented, and the approach used to investigate the topic tends to be anecdotal.

Based on the considerations made in the previous section, the next two sections will present all the current challenges from a strategic perspective deriving from the adoption of 5G for both MNOs and other players involved.

5. Results: 5G business model challenges of MNOs, ecosystem challenges and theory used

According to Oughton et al. (2018), mobile network operators (MNOs) must be aware of both the advantages and the threats coming from the 5G technology paradigm shift. MNOs, who have always played a key role in the telecommunications industry's development (Kuo and Yu, 2006; Funk, 2009; Ghezzi et al., 2015a, 2015b), need to investigate which change 5G is bringing to their business models (Lehr et al., 2021). Such aspect is grounded also in the reasoning presented by Olokundun et al. (2022) who state that today's technology-driven innovations are the recipe for business success, since a business without a technological foundation cannot grow. As they already did when facing earlier technologies, MNOs have adjusted their business models according to the technological potential; however, with the fifth generation, it seems that the development trajectory has changed significantly (Lehr et al., 2021). The Mobile Network operator's (MNOs) challenges derived from the reviewed literature are organised into "Change in the value creation and delivery" and "Unclear revenues and costs streams".

5.1. Current business model challenges of MNOs

5.1.1. Change in value creation and delivery

As shown by Gooderham et al. (2022), MNOs have faced at least three phases during their existence. The first phase took place between 1990 and 2010 with the 2G and the 3G, where mobile operators based their business models on voice, messaging, and elementary connectivity (Lehr et al., 2021). This period represents the rise of MNOs, which were successful in renewing their business by launching a wide range of mobile value-added services and contents. The second phase regards the following decade, from 2010 and 2020, with 4G as the dominant technology, where Internet connectivity became the major revenue stream for MNOs, instead of the previous voice and messaging. However, the attempt to pivot the traditional business models towards the mobile Internet was not as successful as expected due to significant differences and incompatibilities with the legacy business models. This led to a gradual decay of both MNO's focal role in the market. In particular, the MNO market was influenced by the entry of Over the Top (OTT) players, which led to a decrease in the MNO's revenues (Cave, 2018; Matinmikko et al., 2018; Blind and Niebel, 2022). The third phase, which is the period between the previous time windows described and nowadays, is characterised by the advent of 5G and, according to the scholars, the following question arises: "*Will this phase be the rebirth phase for MNOs*?" (Gooderham et al., 2022; p.2).

The main solution drawn by Gooderham et al. (2022) regards all the 5G-enabled services MNOs could offer to enterprises and public players, and it is coherent with what has been presented so far in terms of opportunities enabled by 5G. Therefore, it seems that "*the future of 5G lies in the enterprise, not the consumer market*" (p.9). To do so, MNOs must be able to develop new capabilities, which allow them to co-create digital solutions with business partners to have multiple revenue models; otherwise, the risk is that they will end up offering an "*undifferentiated and price sensitive utility*" (p.8). According to Lemstra (2018), if the MNOs opted to add new revenue streams coming from vertical market offers, their role would be more as a wholesaler of open APIs to enable other players such as Virtual Mobile Network Operator (VMNO) to develop tailored services. In this scenario, regulators and competition authorities will play a crucial role in infrastructure-sharing mechanisms. Lehr et al. (2021) cite the same rationale concerning the increasing per-subscriber capital costs of MNOs in the case of 5G network development. As a matter of fact, they would face huge costs to provide the requested capacity for a local area. However, again, the sharing of infrastructure

could be a solution to cut the per-subscriber costs; therefore, regulators are required.

Conversely, in case they decide to continue pursuing the same strategy in the traditional market (labelled by Lemstra (2018) "Evolution image"), they must strive to conceive services with differentiated quality levels in order to compete (Lemstra, 2018). For instance, Noh et al. (2021) describe the future market in terms of products and services focusing more on the consumer side by mentioning the virtual reality office and online shopping through VR-based remote-control systems and immersive mobile communication product series. They also include the so-called driving environment open-air festival enabled by low-orbit satellite cells and emergency communication. Furthermore, Savunen et al. (2023) analysed two different typologies of MNO Business Models for next-generation public safety services. The main difference concerns the fact that in the so-called "Single actor model", the MNO oversees all the activities, including customer services. In this case, the value proposition is not strictly related to the provision of connectivity services and coverage but encompasses all the other services concerning customer management. Lehr et al. (2021) focus on service models based on the enhanced mobile broadband (eMBB), the niche wide-area and local area networks, including in some way all the applications mentioned so far, where the common factor is high-performance connectivity.

Accordingly, in his work, Cave (2018) presents the possible future structure of the mobile industry, namely: (i) the possibility of sharing active or passive components through the RANs; (ii) more sharing between mobile and fixed networks; (iii) more usage of content delivery networks (CDNs); and (iv) a reduction in the added value of communication services, and an increase in competition between MNOs in delivering value to the verticals industry. Gooderham et al. (2022) mentioned the same rationale for the fourth point presented in Cave (2018) when they defined Telenor's strategic positioning in their study. However, as in 2010 when MNOs were unable to rejuvenate their business model and become a digital service provider, also in the 5G area they could lack the so-called "recombinant firm-specific advantage" (FSAR) to create value from existing assets and new ones (Gooderham et al., 2022), especially considering a revenue growth in the Business-to-Business market. According to the authors, Telenor should acquire competencies and capabilities in IoT, AI, Cloud computing and edge computing to allow digital transformation in numerous industries by providing critical information in a faster and more reliable way.

To conclude, scholars agree on the fact that, even if the telecommunication industry has evolved in recent years, especially with the advent of the Internet, 5G is bringing about several changes that can disrupt the development trajectory of MNO business models (Oughton et al., 2018; Lehr et al., 2021; Gooderham et al., 2022).

5.1.2. Unclear revenues and cost streams

The traditional mission of an MNO is to offer "standardized services at scale". Hence, its aim is then to replicate and scale the solutions in other contexts, but which are the necessary FSARs to do so is still an open issue (Gooderham et al., 2022). Teece (2021) reinforced this consideration by underlining the importance of recognising the heterogeneity of value creation across use cases of the same application (e.g., IoT). However, it is not just a matter of value creation, but of enabling technology such as 5G usually commercialised by downstream firms who own the complementary assets (Teece, 2018a) and are, therefore, favourably positioned in terms of capturing value, which is instead partially lost by the inventor (Rathje and Katila, 2021).

Furthermore, building the 5G infrastructure to deploy services and enable the opportunities promised requires a large investment (Bauer and Bohlin, 2022). For instance, Lehr et al. (2021) mention the need for more cellular base stations, the re-architecting of the radio access network (RAN), and the expansion of radio-frequency spectrum resources to concretise the opportunities promised by 5G. Considering the expected value and possible revenues, as well as the possibility of renewing their strategic positioning within the telecommunications industry, MNOs need to understand how to solve this trade-off between costs and expected value. If, on the one hand, suppliers of equipment and infrastructures have a naturally strong incentive to push the roll-out of 5G (Blind and Niebel, 2022), on the other hand, MNOs are still looking for a business case that could justify the initial investment; moreover, they are hesitant considering also what happened with the previous generation (4G) when the OTTs disrupted their business model. Schneir et al. (2019) reinforce this rationale by explicitly saying that until now few authors have discussed 5G revenues and cost streams, and how to build a sustainable business model. Schneir and colleagues (2022) investigated the issue by looking at the possible business cases a mobile network operator could implement in a seaport area. Similarly, Henriquez and colleagues (2022) mark the difference between "structural connectivity" and "strategic connectivity" in seaports, once again underscoring the necessity to consider such investment as a source of competitive advantage for companies. In line with this, Noh et al. (2021) outline the challenges regarding the connection between technology resources and business objectives by underlining the importance of considering technology a fundamental asset for strategic planning, and by introducing the need for a "technology-driven strategy". Accordingly, Oughton et al. (2018) mentioned the necessity to focus on network reliability and capacity expansion to meet consumer and industrial requirements. Taking this action involves deciding under uncertain circumstances. In their research, scholars try to quantify this uncertainty by comparing the long-term performance of various strategic decisions. They defined four different approaches concerning the improvement of the network by adding capacity or, in a more conservative way, by doing minimum intervention to continue to operate. However, as stated by the authors, the mobile communication industry is a very fast and uncertain environment (Ghezzi et al., 2015a, 2015b) where it is very hard to predict outcomes.

Table 5 provides a brief summary by organising the main business model challenges MNOs currently face.

Table 5
Current business model-related challenges of MNOs.

Current business model challenges of MNOs		
Challenge	*Sub-challenges*	*References*
Change in value creation and delivery	Change in the value proposition, which is more oriented on customisation and high performance in different industrial verticals	Lehr et al., 2021; Matinmikko et al., 2018; Oughton et al., 2018 Gooderham et al., 2022; Cave, 2018
	Risk of selling 5G as an undifferentiated and price sensitive commodity	Gooderham et al., 2022; Oughton et al., 2018 Gooderham et al., 2022; Cave, 2018
	Selling enhanced experience also in the B2C market	Noh et al., 2021; Savunen et al., 2023
	Co-creation of digital solutions with business partners, utilisation of open APIs	Lemstra, 2018; Gooderham et al., 2022
	Development of new competencies and capabilities in IoT, AI, Cloud computing, edge computing	Gooderham et al., 2022
	Need for closer collaboration with various local service providers	Matinmikko et al., 2018
	Focus on network reliability and capacity expansion in terms of infrastructure resources	Oughton et al., 2018
Unclear revenues and cost streams	High investment in infrastructures and resources	Bauer and Bohlin, 2022
	Difficulties in capturing part of the value created, being an enabling technology	Rathje and Katila, 2021
	Difficulties in measuring benefits and costs of a business case	Rendon and Schneir,2019; Schneir et al., 2022; Blind and Niebel, 2022

After having investigated the current strategic challenges of MNOs, the following paragraphs will present an overview of the strategic implications for other actors belonging to the 5G ecosystem. As a matter of fact, 5G is less "MNO-centric" than previous technologies, since it potentially engages many stakeholders, especially with the possibility of deploying private, standalone 5G networks in different vertical industries (Lehr et al., 2021). In these terms, greater attention must be given to all opportunities that are not strictly connected to the MNOs, especially by considering that if operators do not rejuvenate their business models, they run the risk of having specialised players sabotaging their strategic positioning (Bauer and Bohlin, 2022). On the other hand, if MNOs continue to pursue the same role as suppliers of connectivity, they will risk losing competitiveness, as they would get stuck in providing a commodity. Therefore, enterprises other than MNOs need to figure out how to develop a sustainable 5G business model in uncertain conditions (Moqaddamerad and Tapinos, 2023). This rationale finds grounds, for instance, in the work of Henriquez and colleagues (2022, p.1) when they mention the "strategic connectivity" in ports in substitution of the more traditional structural one. In these terms, 5G technology adoption might have a strategic impact and, since its roll-out will involve different vertical industries (Dolgui and Ivanov, 2022), the necessity to find a 5G application characterised by a sustainable business model where benefits overcome investment costs emerges as well.

5.2. 5G Ecosystem challenges

The digital transition caused by 5G introduces many challenges that need further investigation (Lee and Yu, 2022): in particular, how companies could improve their performance by adopting 5G in a specific field is still an open issue (Dolgui and Ivanov, 2022). This is not a new dynamic, especially if 5G is considered an emerging technology (Rotolo et al., 2015), which is often associated with uncertainty and low legitimacy (Ahokangas et al., 2021). Actors involved perceive several risks in adopting the new technology, and they are also characterised by heterogeneous interests (Blind and Niebel, 2022). Massaro and Kim (2022) distinguish between non-private actors, which are government, research institutes, universities and users; private actors, which are MNOs, equipment manufacturers, service providers; and "new actors", intended as additional players that join the ecosystem due to new opportunities the technology could bring. For instance, global service providers such as Amazon, Google and Microsoft could become competitors of the existing players (Gooderham et al., 2022). Knieps and Bauer (2022) put emphasis also on the importance of third-party providers such as system integrators and local network operators, which could play a crucial role in building solutions for local industrial networks. One of the main challenges for stakeholders involved is, therefore, to understand the heterogeneous needs of specific vertical industries, and the capability to exploit upstream 5G network and downstream local applications to develop tailored solutions (Matinmikko et al., 2018; Lemstra, 2018; Knieps and Bauer, 2022).

Another challenge concerns the degree of interconnection of local industrial networks to outside ones (Knieps and Bauer, 2022). As a matter of fact, there are different deployment solutions that oscillate between the two extreme cases, which are either having an isolated local industrial private network or solutions that exploit the public network (Knieps and Bauer, 2022). Ahokangas et al. (2021) define two types of non-public network (NPN): (i) a stand-alone NPN system that is completely isolated from the MNO network; and (ii) a non-public network that is partially based on the MNO infrastructure. However, in the 5G era, private companies play a crucial role in the deployment of such private networks, since MNOs no longer monopolise the network business, as happened with 3G and 4G. With specific reference to industrial IoT scenarios, private enterprises can obtain licenses to deploy their own industrial network (Lehr et al., 2021; Lee and Yu, 2022). This is what happened, for instance, in Germany, where private companies such as Bosch can build their own 5G solutions (Knieps and Bauer, 2022). In these terms, greater attention must be given to all opportunities that are not strictly connected to the MNOs.

Due to the high number of actors involved, several scholars utilise the concept of "data platform ecosystem" (e.g., Ahokangas et al., 2021; Kaartemo and Nyström, 2021; Massaro and Kim, 2022) to describe the industrial verticals where wireless connectivity is integrated with other ICT infrastructures (Ahokangas et al., 2021). Consequently, the presence of a multitude of stakeholders and the possibility of playing different roles in such a "platform constellation" (Ahokangas et al., 2021) require further investigation.

Whereas there may be many local industrial networks and several actors involved in them, two challenges must be addressed, namely the costs of coordination and complementary assets (Bauer and Bohlin, 2022). The first one includes both the transaction costs among players and the costs needed for adapting the technology to specific requirements. The complementary assets are, instead, necessary for the development of applications; therefore, it is essential to foster synergies between interdependent components (Knieps and Bauer, 2022). Moreover, it may happen that innovation comes from the so-called "peripheral technologies", which act "as a platform for market shaping" (Kaartemo and Nyström, 2021). For instance, this is the case of the healthcare market, where 5G-based solutions are not implemented by a single actor but by different actors not traditionally from the industry (Kaartemo and Nyström, 2021). This dynamic complicates the innovation process since it requires great coordination efforts and complementary assets that imply higher costs.

To frame the possible different players belonging to the 5G ecosystem, Bauer and Bohlin (2022) distinguish between four different layers, and place the various players depending on their core competencies and business strategies. The lower part presents passive and active infrastructure layers, which constitute the physical network layer. In the upper part, we find the enablers on the development layer, and the application service layer. On the top layer, we find the end user, while an orchestrator provider is present on each layer. Similarly, Teece (2021) identifies three layers; in particular, the author differentiates between layer zero, called "enabling technology", layer one, which constitutes the "physical infrastructure", and layer two, labelled the "equipment deployment and networking service". In both cases, there is a clear distinction between the network and service deployment, thus also implying the need for different actors to develop each of these elements.

Going in deeper, Ahokangas et al. (2021) deepen key stakeholders' roles in a port ecosystem. Once again, what emerges is the presence of a multitude of actors, ranging from private companies such as cargo owners and logistics companies to connectivity platform providers that guarantee the right level of connection. Digital service providers, which guarantee digital services and physical port infrastructure, are also present. Finally, authorities who manage the port's governance play an active role. In their research, the scholars propose alternative platform configurations, namely the fragmented, centralised and hybrid platforms. In the first case, each actor has its own connectivity and data platform configuration to meet its requirements. In the second case, there is a central coordinating player for both the data and the connectivity service. Finally, in the hybrid one, even if there is a central player, it does not assume a dominant role, but rather develops selected services aligned with the port's goals. A critical aspect that has emerged from the study is the deployment of tailored service for the port's stakeholders, which can entail the utilisation of virtual network resources, based on a service-level agreement and on the resolution of possible regulatory issues (Ahokangas et al., 2021). However, as already mentioned, it is not certain that MNOs will be able to offer tailor-made solutions to specific demands, which is why Lemstra (2018) states in the "Revolution image" scenario that the new service providers will be MVNOs, while MNOs will be the infrastructure operators and will take on the role of wholesalers. Accordingly, Bauer and Bohlin (2022) mention the mobile virtual network aggregators (MVNAs) and mobile virtual network enablers (MVNEs) as new intermediaries to reduce

Table 6
5G ecosystem challenges.

5G ecosystem challenges		
Challenge	*Sub-challenges*	*References*
Not MNO-centric anymore	Possibility to create stand-alone non-public-networks for private enterprises, which can acquire spectrum licenses without involving MNOs, according to country-specific regulations	Knieps and Bauer, 2022; Ahokangas et al., 2021; Lehr et al., 2021; Lee and Yu, 2022; Bauer and Bohlin, 2022
	The risk of some actors being "sabotaged" by MNOs that do not rejuvenate their business models	Bauer and Bohlin, 2022
	Shift from a small number of dominant MNOs to many local and network operators	Matinmikko et al., 2018; Lemstra, 2018; Bauer and Bohlin (2022)
	Shift from owning the infrastructure to leasing network slicing on-demand	Matinmikko et al., 2018
	Collaboration with governments is open also to other players and not only to MNOs	Lee and Yu, 2022; Rathje and Katila, 2021
High coordination costs and need for complementary assets	Coordination costs include transaction costs among players, and the costs needed for adapting the technology to specific requirements	Bauer and Bohlin, 2022
	Need for complementary assets and a strong collaboration between the stakeholders involved	Knieps and Bauer, 2022; Kaartemo and Nyström, 2021
	Need to have an "orchestrator" or a "central player" who fosters innovation for 5G deployment	Bauer and Bohlin, 2022; Ahokangas et al., 2021
Industrial vertical applications development	The value creation mechanism in specific application fields is still unclear	Dolgui and Ivanov, 2022
	Understanding heterogeneous needs coming from specific vertical industries to develop tailored solutions is required	Matinmikko et al., 2018; Lemstra, 2018; Knieps and Bauer, 2022
	Enabling IoT application for vertical industries at a niche level	Lee and Yu, 2022

coordination costs between the different stakeholders, and to offer specialised services, such as autonomous vehicles, logistics and transport. Accordingly, Matinmikko et al. (2018), in setting the trend concerning the 5G business ecosystem, underline the necessity to move from a small number of dominant MNOs to many local and network operators, as well as from owning the infrastructure to leasing network slicing on-demand.

Another challenge regards the role of the "orchestrator" (Bauer and Bohlin, 2022) or the "central player" (Ahokangas et al., 2021). In both cases, the importance of having a stakeholder acting as a coordinator and cutting through all the layers has been emphasised. It is thus possible to make innovation easier and spur all the actors to contribute to the right direction. Something similar has also been mentioned by Lee and Yu (2022) when describing the role of Huawei in promoting IoT innovations in China. In particular, the company provides all the necessary resources to foster the telecom operators' actions. This action aimed to enable IoT applications for vertical industries at a niche level, and Huawei positioned itself as a leading company to incentivise other actors to operate, especially MNOs. However, as underlined by the scholars, initiatives at a global and national level are also needed, especially concerning the fact that in the 5G era, collaboration with governments is open also to other providers and not only to MNOs (Lee and Yu, 2022). Accordingly, Rathje and Katila (2021) demonstrate the importance of government relations with private firms to pursue all the opportunities an enabling technology offers.

Table 6 summarises the main strategic challenges concerning the 5G ecosystem.

5.3. Theories employed by the extant studies

With reference to the challenges identified in the previous sections, this section aims to review the theoretical lens employed by scholars to deal with the 5G topic. The two tables above have already provided a synthesis of the 23 articles, identifying a series of challenges that have emerged empirically from various studies. However, we aim to clarify which theoretical approaches were used to delve deeper into these challenges.

Firstly, it is worth mentioning that no specific theoretical lens is evident in 9 out of the 23 studies. Specifically, the works by Olokundun et al. (2022), Knieps and Bauer (2022), Dolgui and Ivanov (2022), Teece (2021), Lehr et al. (2021), Lemstra (2018), and Cave (2018) are conceptual papers that describe the phenomenon without employing particular theoretical frameworks. Furthermore, the two studies by Rendon Schneir et al. (2019; 2022) have focused on two specific business cases, with particular attention to cost structures and the stakeholders involved.

With the remaining papers, it was possible to categorise the different theoretical approaches into three main groups, as illustrated in Fig. 2.

Several articles have analysed the challenges of 5G from an actor-specific perspective, considering both provider companies and end-users. In both cases, the theme of Business Model (Teece, 2010; Casadesus-Masanell and Ricart, 2010) and Business Model Innovation (Foss and Saebi, 2017) is recurrent, appearing in 4 studies (Henríquez et al., 2022; Savunen et al., 2023; Moqaddamerad and Tapinos, 2023). This is not a surprise, considering that the concept of the Business Model has already been used in the literature to describe the strategy reflection and execution of MNOs with the previous mobile technologies (Casadesus-Masanell and Ricart, 2010; Ghezzi et al., 2015a, 2015b; Cortimiglia et al., 2016). Furthermore, the theme of the business model is also mentioned in the study by Gooderham et al. (2022); however, the focus is on "firm-specific advantages" (Adarkwah and Malonaes, 2020) concerning MNOs, with specific reference to advantages required to regain the competitive advantage lost in previous years with past mobile telecommunications technologies.

Moqaddamerad and Tapinos (2023) and Noh et al. (2021), rather emphasise defining potential future strategies. This is achieved through the practice of sensemaking (in the former case) or by using technology-driven roadmapping (Jin et al., 2015) in the latter to propose an integrated approach combining a technology-push strategy and a market-driven strategy. The scholars also leverage the Value Proposition Canvas (Osterwalder et al., 2014) to identify potential new products or services with the advent of 5G.

Moreover, there are studies that have shifted the perspective towards a more ecosystemic approach, moving away from a firm-specific focus. Therefore, the literature of "Ecosystem" (Adner, 2017; Jacobides et al., 2018) leveraged has been articulated in forms such as the "multi-stakeholder", "platform" ecosystem (Ahokangas et al., 2021) and the "business" Ecosystem (Matinmikko et al., 2018). In contrast, Lee and Yu (2022) and Bauer and Bohlin (2022) utilise the concepts of a network-based approach (Funk and Methe, 2001) and a value system view, respectively, to describe the technology transition of 5G and how 5G policies impact performance. If, on the one hand, both cases have mapped the actors involved across different layers, a typical aspect of the ecosystem literature, on the other hand they focus on how various regulations influence the technological transition towards 5G and

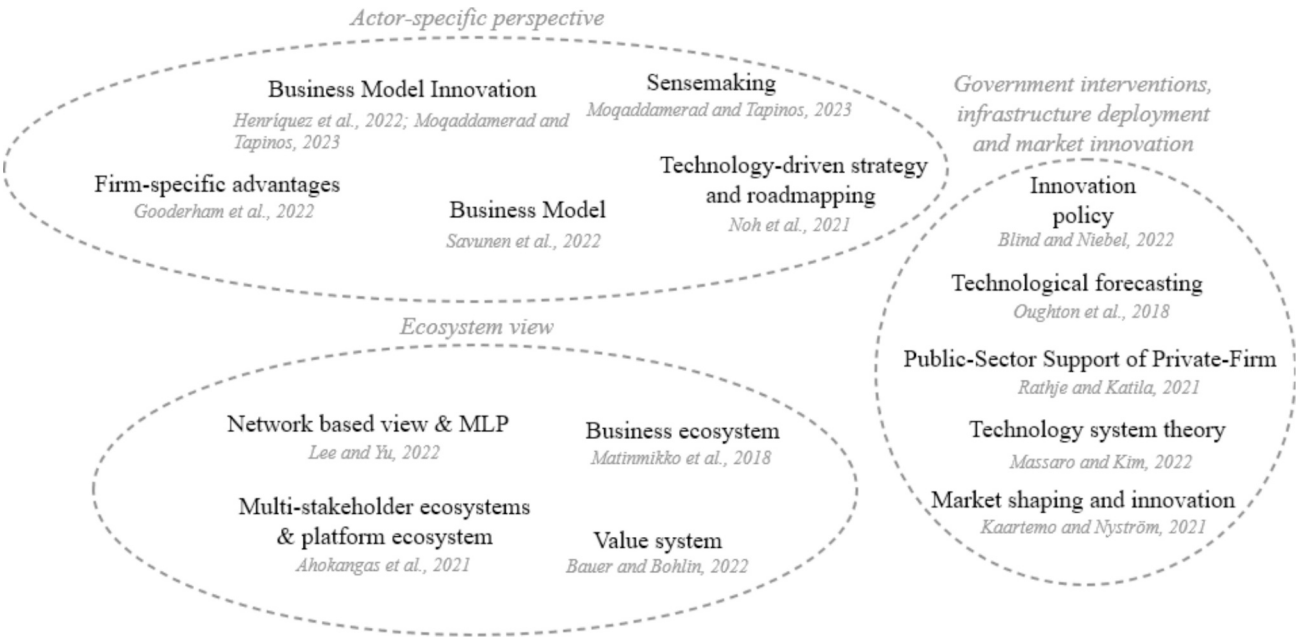

Fig. 2. Theoretical lenses used by scholars to investigate 5G.

infrastructure development.

This is a common feature in 5 of the articles reviewed, which leverage the literature related to market innovation, government interventions, and infrastructure development to address the topic of 5G. These works, although included in the review since they offered interesting insights into the strategic challenges discussed in the previous paragraphs, adopted a different theoretical perspective from the strategic one. In particular, these articles discuss what are the market, system, and transformational systems failures related to 5G roll-out (Blind and Niebel, 2022), or how public support for private companies plays a significant role in the case of enabling technologies (Rathje and Katila, 2021). Kaartemo and Nyström (2021), in turn, focus on market changes induced by 5G in specific contexts, such as healthcare, using market-shaping and innovation theories (Nenonen et al., 2019). Finally, the last two studies concern technological forecasting theories (Oughton et al., 2018) and technology systems (Hughes, 1987; Massaro and Kim, 2022) in specific locations, such as the UK and South Korea, for the infrastructural development of technology.

6. Discussion

What emerged from the previous sections is that papers reviewed present strict boundary conditions, making it difficult to generalise findings. They focus on the pragmatism of the problem itself (e.g., local private networks in ports) to the detriment of an adequate theoretical background. This is even more apparent considering that 9 out of 23 do not even use specific theoretical lenses, and often there is no research question anchored to a specific reference literature.

As shown in Fig. 2, three main perspectives have been used to delve deeper into the topic (actor-specific, ecosystem, market innovation) from a theoretical standpoint. If we leave aside the governmental and infrastructural aspects again, considering that they are not the focus of our research, from a strategic perspective the theoretical lenses used to study the topic are very limited in number and highly fragmented. From the actor-specific perspective, the topics of business model and business model innovation are the most used. However, in the case of Henriquez and colleagues (2022), the focus is entirely on smart ports (and consequently on the specific literature), while in the case of Savunen et al. (2023), the business model of MNOs is built around Public Safety. In this work, the distinction between value creation and delivery is still somewhat blurred, and the topic often intersects with a more "ecosystemic" view, overlapping topics.

The works of Gooderham et al. (2022), Moqaddamerad and Tapinos (2023), and Noh et al. (2021) are the three studies that present a stronger theoretical grounding, detailing the literature on firm-specific advantages (Adarkwah and Malonaes, 2020), business model innovation (Foss and Saebi, 2017), sensemaking (Weick and Weick, 1995), and strategy roadmapping (Jin et al., 2015) to address their respective research questions. However, these few studies still investigate a limited share of the strategic implications of 5G adoption; therefore, we call for further theoretical structuring of the 5G literature stream to intercept the rise of a new technological paradigm, which holds idiosyncratic implications for industry evolution and corporate strategy.

From an ecosystem perspective, while the need to map the actors involved is clear, there is perhaps even more uncertainty regarding the reference literature to be used to study interconnected business models (Jocevski et al., 2020).

To help the 5G strategic literature evolve beyond an anecdotal approach, and to push for more generalisable results, we propose possible theoretical anchors and suggest research questions future research scholars can leverage to strengthen the foundations contributed by their studies, thus preventing 5G strategic literature from suffering from empirical localisation.

Building on the challenges related to the business models of MNOs identified in the previous section, some authors have already used the concept of a business model, as previously mentioned, although they have done so without delving into the mechanisms of 5G business model innovations. As stated in the strategic literature by Foss and Saebi (2017), most studies describe business model innovation in a retrospective manner when considering the adoption of specific technologies. However, the challenge of 5G research is related to the need to conduct analyses and make proposals while the 5G rollout and implementation are still ongoing, meaning that research is being conducted in medias res.

Similarly, Baden-Fuller and Haefliger (2013) and Tongur and Engwall (2014) highlight that the impact of adopting technology is often limited to performance measurements. However, the link between technology and performance is more straightforward to investigate once the technology is fully adopted, which is not yet the case for 5G. The performance determinants, rooted in the business model architecture,

and the mechanisms for innovating 5G business models in terms of new ways to create, deliver, and capture value, require further investigation (Ancillai et al., 2023).

Furthermore, 5G currently presents a strategic dilemma. According to Tongur and Engwall (2014), a business model dilemma may arise when a company must decide whether to focus on a value proposition tied to a specific technological innovation or one that is independent of the core technology but centres on technology-enabled services. This situation creates challenges for MNOs in terms of both value creation and capture (Teece, 2018a, 2018b; Sjödin et al., 2020), as discussed in the previous section: on the one hand, they need to innovate their strategy by developing new resources and competencies (e.g., IoT, AI, Cloud computing, edge computing) to attract new customers (e.g., Enterprises for the deployment of 5G private networks); on the other hand, they must ensure they capture a significant portion of the value generated by 5G to avoid becoming just a "commodity provider" and falling into a potential price war already taking place in the B2C market.

However, given the nature of 5G as an enabling technology (Knieps and Bauer, 2022; Rathje and Katila, 2021; Teece, 2018a, 2018b), a further dimension must be considered in their strategic decisions, precisely the horizontal scope of commercialisation (Gambardella et al., 2021). Indeed, due to the multiple fields of application enabled by ET, the strength of the innovator's ability to appropriate value (such as through technology licensing) may be diminished (Gambardella et al., 2021), necessitating a range of complementary assets. Conti et al. (2019) demonstrate, in the laser industry, that when entering downstream markets is not advantageous and intermediate markets function well, innovators may benefit from refraining from entering the downstream market and, instead, focus on licensing the ET, while specialising in generality as a long-term strategy.

For MNOs, intermediate markets are not yet fully functional (as there is neither clear demand nor supply), and they have already invested heavily in core 5G resources such as licenses and infrastructure. They need to innovate their strategy by deciding whether to focus on selling customised 5G applications for specific verticals or the technology itself, and must navigate the broader commercialisation scope of ET, focusing on the 5G technicalities that can make it versatile.

By investigating these issues, it is also possible to contribute to the General-Purpose Technology literature (Bresnahan and Trajtenberg, 1995) where, only recently, studies have begun to move away from a predominantly "economic" perspective in dealing with these technologies, and are starting to focus on firm-specific challenges. Existing works mainly concern upstream companies that own the technology (patents), so the discussions are more aligned with a knowledge-based view (Gambardella and McGahan, 2010). Nonetheless, the commercialisation of enabling technologies has not yet been fully explored even for downstream actors (including MNOs), as empirically shown by this research. Furthermore, the analysis of the 5G, a technology which is still a junior GPT (Teece, 2018a, 2018b) allows to investigate GPT in a non-retrospective manner and without ex-post recognition, as most studies do (Magistretti et al., 2019).

Moreover, considering that 5G is predominantly oriented towards the business and industrial markets, (Lehr et al., 2021; Matinmikko et al., 2018; Oughton et al., 2018; Gooderham et al., 2022; Cave, 2018), especially for what concerns the deployment of private, standalone 5G networks (Lehr et al.,2021), as well as the necessity to collaborate with other industrial verticals (Gooderham et al., 2022; Matinmikko et al., 2018), MNOs may realise that giving up their focal position is not a failure per se, but may rather uncover new opportunities for business collaboration and partnership to seize the full potential of 5G.

This presents implications at firm-specific and ecosystem-specific levels. From a firm-specific perspective, it is essential to understand what new opportunities, resources and competencies are needed, and how to manage such uncertainty arising from this new direction. It could be extremely interesting to explore these topics further by using the literature on dynamic capabilities (Teece, 2018a, 2018b) and sensemaking (Weick, 1995), since they are two well-developed literatures that have already made a strong contribution in other areas. For the latter, Moqaddamerad and Tapinos' work (2023) has already delved into the practice of sensemaking and business model innovation, but the study calls for new work that can verify the results, such as in MNOs or 5G adopters. For the former, the capacity to sense, seize, and reconfigure a company's intangible and tangible assets (Teece, 2007) may be an interesting perspective to delve into. This aspect can also be linked to the literature, where, for example, Gooderham et al. (2022) mentioned that MNOs' firm-specific advantages are still uncertain, and such a theoretical perspective could contribute to this direction of investigation. Furthermore, the theme of dynamic capabilities has also been associated with the theme of ecosystem leadership (Foss et al., 2023), and this perspective could be very interesting to assess a potential orchestrator role for MNOs, since it has often been mentioned in the current literature that the 5G ecosystem is much less "MNO-centric" than previous generations (Knieps and Bauer, 2022; Bauer and Bohlin, 2022), especially due to the possibility of developing private networks. In fact, potential coordination and cooperation issues could be mitigated with ecosystem leadership dynamic capabilities (Foss et al., 2023). However, no one has discussed what MNOs could do from this perspective, but the role of different actors has been observed in specific areas (e.g., Ahokangas et al., 2021). Therefore, this theoretical lens could help deepen the topic, and at the same time, 5G and the situation of MNOs could become an excellent empirical field to address more theoretical research questions.

Multiple research questions arise from an ecosystem perspective (Adner and Kapoor, 2010; Adner, 2017; Jacobides et al., 2018). Indeed, through the literature on platform-based business models and B2B digital platforms (Adner, 2017; Jacobides et al., 2018; Jovanovic et al., 2022), it could be useful to investigate how, today, controlling the market through a "walled garden" approach, as MNOs used to do during the 3G era (Ghezzi et al., 2015a, 2015b), is not only unrealistic but also inefficient. For instance, in the reviewed papers, the possibility for MNOs to turn 5G into an open platform and make APIs accessible for monetization is mentioned. However, it is unclear how the process of value creation, delivery, and capture occurs and whether MNOs could effectively act as the orchestrators of the 5G platform. Furthermore, B2B platforms do not follow the "winner-takes-all" mantra of B2C platforms but rather bring to light new complexities (Saadatmand et al., 2019). The current technological and business complexity calls for a strategic positioning that is deeply embedded within an ecosystem, where resources and competencies can be effectively recombined with those of MNOs to collectively renew business models and shape platform ecosystems (Cozzolino et al., 2021; Kazantsev et al., 2023). However, this introduces a series of challenges regarding who will be the orchestrator of the ecosystem, whether it is needed, if there will be just one, how it will emerge, and what competencies it will possess. The literature on ecosystems is gaining momentum in recent years and 5G could serve as an excellent empirical field to contribute to this stream of research. In the reviewed works, the ecosystem approach has already been utilised in four studies (Lee and Yu, 2022; Matinmikko et al., 2018; Ahokangas et al., 2021; Bauer and Bohlin, 2022). However, as extensively discussed previously, this perspective has mainly been used to map the actors, and the boundary conditions are quite restrictive (e.g., context-specific). Instead, the literature about orchestrator's capabilities (Foss et al., 2023) or on the management of complementors (Hannah and Eisenhardt, 2018) can be very helpful in understanding the topic, especially considering the enabling technological nature of 5G, where complementors are crucial for building a value proposition based on numerous use cases. Moreover, the literature on complementors is both "confused and complex" (Teece, 2018a, 2018b; p.1373), and various scholars have recently attempted to define the different types of complementors, (Jacobides et al., 2018; Hannah and Eisenhardt., 2018; Adner and Lieberman, 2021), where the distinction between complementor and the focal firm does not depend on being the innovator or not, but may rather depend on the role played within the ecosystem

Table 7
5G strategic challenges: suggested theoretical anchors and possible research questions.

Strategic challenges that emerged from the 5G literature		Ongoing literature debate and suggested theoretical anchors	Possible research questions
Current Business model challenges of MNOs	Change in the value creation and delivery	▪ Business Model innovation (Foss and Saebi, 2017) and Digital Business Model archetype (Ancillai et al., 2023)	How do the mechanisms to create and deliver value from 5G change in the business model of MNOs?
			What are possible scenarios in terms of new MNOs' 5G business model archetypes?
		▪ Servitization (Tongur and Engwall, 2014; Sjödin et al., 2020)	How can MNOs orient themselves towards a servitization strategy in 5G commercialisation?
		▪ Sensemaking (Weick, 1995; Moqaddamerad and Tapinos, 2023)	How can MNOs deal with business model innovation uncertainties in 5G technology?
		▪ Dynamic capabilities (Teece, 2018a, 2018b)	How can MNOs sense and seize 5G opportunities?
	Unclear revenues and cost streams	▪ Knowledge-based view (Gambardella and McGahan, 2010)	How can MNOs pursue a strategy in generality when intermediate still does not work? How does the licensing process take place with other downstream actors?
		▪ Specialisation in generality (Conti et al., 2019)	How is the trade-off managed by MNOs between the horizontal scope of 5G commercialisation, and offering a customised service for the domain of different verticals? how does the value capture process take place?
5G ecosystem challenges	Not MNO-centric anymore	▪ Platform-based business models (Adner, 2017; Jacobides et al., 2018; Cozzolino et al., 2021)	How can 5G evolve into a GPT by becoming pervasive in multiple verticals?
		▪ Business-to-Business Digital Platforms (Jovanovic et al., 2022)	How does the process of ecosystem emergence occur in the case of 5G?
			How can ecosystem leaders manage B2B platforms like 5G?
	High coordination costs and need for complementary assets	▪ Alignment of complementors (Hannah and Eisenhardt, 2018)	How can the orchestrator coordinate downstream complementors to support the development of 5G-enabled applications in different verticals?
		▪ Ecosystem leadership (Foss et al., 2023)	Is the figure of the orchestrator necessary?
			Will it be the focal company or another actor/multiple actors?
	Industrial vertical applications development		Which are the conditions under which they result in the emergence of one leader or divided leadership within the 5G ecosystem due to the potential broad scope of commercialisation?

(Adner and Kapoor, 2010; Adner, 2017; Jacobides et al., 2018). This perspective could be very interesting for analysing the positioning of MNOs relative to other actors, particularly in relation to the fact that, as core product firms, they may not necessarily have to be the orchestrators. This could contribute to the current debate on the role of "end-to-end orchestrator" and "central player" (Bauer and Bohlin, 2022; Ahokangas et al., 2021).

These reflections have been summarised below in Table 7, grouping them under "Ongoing literature debate and suggested theoretical anchors" and "Possible research questions."

7. Conclusion

This study aims to take stock and systematise extant knowledge on 5G adoption from a strategic perspective by identifying the main implications, challenges and setting for future research avenues with suggested theoretical anchors.

According to the literature, due to its pervasiveness and the number of application fields that can be enabled, 5G is defined as an enabling technology (Teece, 2018a, 2018b; Schneir et al., 2019; Rathje and Katila, 2021). This enabling trait is also confirmed by looking at the promised value resulting from the adoption of this technology, especially for MNOs, which must rejuvenate their business models to make the most out of 5G (Lehr et al., 2021; Gooderham et al., 2022). Focus is often placed on 5G infrastructural requirements, which can involve both extensive coverage or the deployment of 'non-public' networks at the enterprise customer, as well as the regulatory aspect, particularly regarding public incentives and management of the 5G spectrum.

Though they are very important contextual factors, there is also a clear strategic issue for the stakeholders involved, particularly the MNOs. However, few papers have solid strategic theoretical foundations, often focusing on very specific aspects that remain difficult to generalise due to the boundary conditions and idiosyncrasies that emerge, revealing a misalignment between the theory employed and the actual problem. Hence, we claim that from a theoretical standpoint, researching the potential evolution of business models adopted by MNOs and all other actors belonging to the 5G ecosystem could be highly intriguing, as 5G could provide an excellent empirical field to address research questions arising from current debates in strategic literature, such as business model innovation (Foss and Saebi, 2017) and ecosystem (Adner, 2017).

This work contributes to positioning 5G within management literature. In particular, we help advance the literature on 5G by proposing several theoretical anchors and possible research questions to move beyond anecdotal approaches, aiming to obtain results that can be generalised to other contexts or other enabling technologies. A synthesis has been made of all the strategic challenges emerging from the reviewed papers, both from the perspective of MNOs and of the entire ecosystem. This includes not only challenges related to infrastructure development and regulatory issues but also an organised overview of the current open questions regarding value creation and capture, from the standpoint of MNOs and other actors. Furthermore, by proposing some theoretical streams that can help investigate these issues, 5G is presented as a very interesting and unique empirical field in which more theoretical research questions can be explored.

For what concerns the implications for practice, our research emphasises the potential of 5G technology, which is far from being a mere incremental innovation when compared to its predecessors. In our study, we delve into the multitude of opportunities that 5G can enable from a strategic perspective, and provide a comprehensive exploration of the diverse actors who can benefit from its implementation.

Although 5G has already reached a commendable level of

technological maturity, 5G stakeholders find themselves in a market that is still struggling to gain the momentum it deserves. The emergence of 5G has compelled several industries, from healthcare to manufacturing, to recognise its potential for transformation; therefore, the necessity to build a dynamic and interconnected ecosystem not only refers to the telecommunications industry but also spans beyond its boundaries. In sum, while 5G technology has indeed reached a significant level of technological maturity, it is essential to acknowledge that the market has yet to fully embrace its transformative power. This pivotal moment calls upon stakeholders to unite, innovate, and forge sustainable pathways to understand how to create and capture the vast value promised by 5G technology.

CRediT authorship contribution statement

Mattia Magnaghi: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Formal analysis, Conceptualization. **Antonio Ghezzi:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Andrea Rangone:** Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

None.

Data availability

No data was used for the research described in the article.

References

Adarkwah, G.K., Malonaes, T.P., 2020. Firm-specific advantages: a comprehensive review with a focus on emerging markets. Asia Pac. J. Manag. 1–47.

Adhikari, M., Hazra, A., 2022. 6G-enabled ultra-reliable low-latency communication in edge networks. IEEE Communications Standards Magazine 6 (1), 67–74. https://doi.org/10.1109/MCOMSTD.0001.2100098.

Adner, R., 2017. Ecosystem as structure: an actionable construct for strategy. J. Manag. 43 (1), 39–58. https://doi.org/10.1177/0149206316678451.

Adner, R., Kapoor, R., 2010. Value creation in innovation ecosystems: how the structure of technological interdependence affects firm performance in new technology generations. Strateg. Manag. J. 31 (3), 306–333. https://doi.org/10.1002/smj.821.

Adner, R., Lieberman, M., 2021. Disruption through complements. *Strategy*. Science 6 (1), 91–109.

Ahokangas, P., Matinmikko-Blue, M., Yrjölä, S., Hämmäinen, H., 2021. Platform configurations for local and private 5G networks in complex industrial multi-stakeholder ecosystems. Telecommun. Policy 45 (5), 102128. https://doi.org/10.1016/j.telpol.2021.102128.

Ancillai, C., Sabatini, A., Gatti, M., Perna, A., 2023. Digital technology and business model innovation: a systematic literature review and future research agenda. Technol. Forecast. Soc. Chang. 188, 122307. https://doi.org/10.1016/j.techfore.2022.122307.

Baden-Fuller, C., Haefliger, S., 2013. Business models and technological innovation. Long Range Plan. 46 (6), 419–426. https://doi.org/10.1016/j.lrp.2013.08.023.

Balmer, R.E., Levin, S.L., Schmidt, S., 2020. Artificial intelligence applications in telecommunications and other network industries. Telecommun. Policy 44 (6), 101977. https://doi.org/10.1016/j.telpol.2020.101977.

Bauer, J.M., Bohlin, E., 2022. Regulation and innovation in 5G markets. Telecommun. Policy 46 (4), 102260. https://doi.org/10.1016/j.telpol.2021.102260.

Blind, K., Niebel, C., 2022. 5g roll-out failures addressed by innovation policies in the EU. Technol. Forecast. Soc. Chang. 180, 121673. https://doi.org/10.1016/j.techfore.2022.121673.

Bresnahan, T.F., Trajtenberg, M., 1995. General purpose technologies 'engines of growth'? J. Econ. 65 (1), 83–108. https://doi.org/10.1016/0304-4076(94)01598-T.

Buggenhagen, M., Blind, K., 2022. Development of 5G – identifying organizations active in publishing, patenting, and standardization. Telecommun. Policy 46 (4), 102326. https://doi.org/10.1016/j.telpol.2022.102326.

Casadesus-Masanell, R., Ricart, J.E., 2010. From strategy to business models and onto tactics. Long Range Plan. 43 (2-3), 195–215.

Cave, M., 2018. How disruptive is 5G? Telecommun. Policy 42 (8), 653–658. https://doi.org/10.1016/j.telpol.2018.05.005.

Conti, R., Gambardella, A., Novelli, E., 2019. Specializing in general purpose technologies as a firm long-term strategy. Ind. Corp. Chang. 28 (2), 351–364. https://doi.org/10.1093/icc/dty069.

Cortimiglia, M.N., Ghezzi, A., Frank, A.G., 2016. Business model innovation and strategy making nexus: evidence from a cross-industry mixed-methods study. R&D Manag. 46 (3), 414–432.

Cozzolino, A., Corbo, L., Aversa, P., 2021. Digital platform-based ecosystems: the evolution of collaboration and competition between incumbent producers and entrant platforms. J. Bus. Res. 126, 385–400.

de Oliveira, U.R., Menezes, R.P., Fernandes, V.A., 2023. A systematic literature review on corporate sustainability: contributions, barriers, innovations and future possibilities. Environ. Dev. Sustain. 1-35. https://doi.org/10.1007/s10668-023-02933-7.

Dolgui, A., Ivanov, D., 2022. 5G in digital supply chain and operations management: fostering flexibility, end-to-end connectivity and real-time visibility through internet-of-everything. Int. J. Prod. Res. 60 (2), 442–451. https://doi.org/10.1080/00207543.2021.2002969.

Du Preez, G.T., Pistorius, C.W., 2003. Analyzing technological threats and opportunities in wireless data services. Technol. Forecast. Soc. Chang. 70 (1), 1–20. https://doi.org/10.1016/S0040-1625(02)00253-6.

Erokhin, D., Yosipof, A., Komendantova, N., 2022. COVID-19 conspiracy theories discussion on twitter. Social media+ society 8 (4). https://doi.org/10.1177/20563051221126051, 20563051221126051.

Forge, S., Vu, K., 2020. Forming a 5G strategy for developing countries: a note for policy makers. Telecommun. Policy 44 (7), 101975. https://doi.org/10.1016/j.telpol.2020.101975.

Foss, N.J., Saebi, T., 2017. Fifteen years of research on business model innovation. J. Manag. 43 (1), 200–227. https://doi.org/10.1177/0149206316675927.

Foss, N.J., Schmidt, J., Teece, D.J., 2023. Ecosystem leadership as a dynamic capability. Long Range Plan. 56 (1), 102270.

Friis, K., Lysne, O., 2021. Huawei, 5G and security: technological limitations and political responses. Dev. Chang. 52 (5), 1174–1195. https://doi.org/10.1111/dech.12680.

Funk, J.L., 2009. The emerging value network in the mobile phone industry: the case of Japan and its implications for the rest of the world. Telecommun. Policy 33, 4–18. https://doi.org/10.1016/j.telpol.2008.09.002.

Funk, J.L., Methe, D.T., 2001. Market-and committee-based mechanisms in the creation and diffusion of global industry standards: the case of mobile communication. Res. Policy 30 (4), 589–610.

Gambardella, A., Heaton, S., Novelli, E., Teece, D.J., 2021. Profiting from enabling technologies? Strategy Science 6 (1), 75–90.

Gambardella, A., McGahan, A.M., 2010. Business-model innovation: general purpose technologies and their implications for industry structure. Long Range Plan. 43 (2–3), 262–271.

García, J.A., Rodriguez-Sánchez, R., Fdez-Valdivia, J., 2011. Overall prestige of journals with ranking score above a given threshold. Scientometrics 89 (1), 229–243. https://doi.org/10.1007/s11192-011-0442-6.

Gebauer, H., Arzt, A., Kohtamäki, M., Lamprecht, C., Parida, V., Witell, L., Wortmann, F., 2020. How to convert digital offerings into revenue enhancement–conceptualizing business model dynamics through explorative case studies. Ind. Mark. Manag. 91 (429), 441. https://doi.org/10.1016/j.indmarman.2020.10.006.

Ghezzi, A., Balocco, R., Rangone, A., 2015a. A fuzzy framework assessing corporate resource management for the mobile content industry. Technol. Forecast. Soc. Chang. 96, 153–172.

Ghezzi, A., Cortimiglia, M.N., Frank, A.G., 2015b. Strategy and business model design in dynamic telecommunications industries: a study on italian mobile network operators. Technol. Forecast. Soc. Chang. 90, 346–354. https://doi.org/10.1016/j.techfore.2014.09.006.

Ghezzi, A., Gabelloni, D., Martini, A., Natalicchio, A., 2018. Crowdsourcing: a review and suggestions for future research. Int. J. Manag. Rev. 20 (2), 343–363.

Gooderham, P., Elter, F., Petersen, T., Sandvik, A., 2022. The digital challenge for multinational mobile network operators. More marginalization or rejuvenation? SSRN Electron. J. https://doi.org/10.1016/j.intman.2022.100946.

Hannah, D.P., Eisenhardt, K.M., 2018. How firms navigate cooperation and competition in nascent ecosystems. Strateg. Manag. J. 39 (12), 3163–3192.

Hardell, L., Carlberg, M., 2021. Lost opportunities for cancer prevention: historical evidence on early warnings with emphasis on radiofrequency radiation. Rev. Environ. Health 36 (4), 585–597. https://doi.org/10.1515/reveh-2020-0168.

Hasanah, U., Sukoco, B.M., Supriharyanti, E., Wu, W.Y., 2023. Fifty years of artisan entrepreneurship: a systematic literature review. J. Innov. Entrep. 12 (1), 46. https://doi.org/10.1186/s13731-023-00308-w.

Henríquez, R., Martínez de Osés, F.X., Martínez Marín, J.E., 2022. Technological drivers of seaports' business model innovation: an exploratory case study on the port of Barcelona. Res. Transp. Bus. Manag. 43, 100803. https://doi.org/10.1016/j.rtbm.2022.100803.

Higgins, J.P.T., Green, S., 2011. Cochrane Handbook for Systematic Reviews of Interventions. Version 5.1.0. In: The Cochrane Collaboration. http://handbook-5-1.cochrane.org.

Hughes, T.P., 1987. The evolution of large technological systems. In: Bijker, W.E., Hughes, T., Pincn, T. (Eds.), The Social Construction of Technological Systems. The MIT Press, Cambridge, pp. 51–82.

Huynh, M.T., Nippa, M., Aichner, T., 2023. Big data analytics capabilities: patchwork or progress? A systematic review of the status quo and implications for future research. Technol. Forecast. Soc. Chang. 197, 122884. https://doi.org/10.1016/j.techfore.2023.122884.

Iranpak, S., Shahbahrami, A., Shakeri, H., 2021. Remote patient monitoring and classifying using the internet of things platform combined with cloud computing. J. Big Data 8, 1–22. https://doi.org/10.1186/s40537-021-00507-w.

Jacobides, M.G., Cennamo, C., Gawer, A., 2018. Towards a theory of ecosystems. Strateg. Manag. J. 39 (8), 2255–2276. https://doi.org/10.1002/smj.2904.
Jin, G., Jeong, Y., Yoon, B., 2015. Technology-driven roadmaps for identifying new product/market opportunities: use of text mining and quality function deployment. Adv. Eng. Inform. 29 (1), 126–138.
Jocevski, M., Arvidsson, N., Ghezzi, A., 2020. Interconnected business models: present debates and future agenda. J. Bus. Ind. Mark. 35 (6), 1051–1067. https://doi.org/10.1108/JBIM-06-2019-0292.
Jovanovic, M., Sjödin, D., Parida, V., 2022. Co-evolution of platform architecture, platform services, and platform governance: expanding the platform value of industrial digital platforms. Technovation 118, 102218.
Kaartemo, V., Nyström, A.G., 2021. Emerging technology as a platform for market shaping and innovation. J. Bus. Res. 124, 458–468. https://doi.org/10.1016/j.jbusres.2020.10.062.
Kazantsev, N., Islam, N., Zwiegelaar, J., Brown, A., Maull, R., 2023. Data sharing for business model innovation in platform ecosystems: from private data to public good. Technol. Forecast. Soc. Chang. 192, 122515.
Kim, J., Park, K., 2022. 6G and the internet of things: topic analysis. Journal of Industrial Integration and Management 7 (04), 535–553. https://doi.org/10.1142/S2424862222500038.
Knieps, G., Bauer, J.M., 2022. Internet of things and the economics of 5G-based local industrial networks. Telecommun. Policy 46 (4), 102261. https://doi.org/10.1016/j.telpol.2021.102261.
Kuo, Y., Yu, C., 2006. 3G telecommunication operators' challenges and roles. a perspective of mobile commerce value chain 12 (26), 1347–1356. https://doi.org/10.1016/j.technovation.2005.08.004. Technovation.
Kuś, A., Massaro, M., 2022. Analysing the C-band spectrum auctions for 5G in Europe: achieving efficiency and fair decisions in radio spectrum management. Telecommun. Policy 46 (4), 102286. https://doi.org/10.1016/j.telpol.2021.102286.
Lee, C.-K., Yu, L., 2022. A multi-level perspective on 5G transition: the China case. Technol. Forecast. Soc. Chang. 182, 121812. https://doi.org/10.1016/j.techfore.2022.121812.
Lehr, W., Queder, F., Haucap, J., 2021. 5G: a new future for mobile network operators, or not? Telecommun. Policy 45 (3), 102086. https://doi.org/10.1016/j.telpol.2020.102086.
Lemstra, W., 2018. Leadership with 5G in Europe: two contrasting images of the future, with policy and regulatory implications. Telecommun. Policy 42 (8), 587–611. https://doi.org/10.1016/j.telpol.2018.02.003.
Lin, X., 2022. An overview of 5G advanced evolution in 3GPP release 18. IEEE Communications Standards Magazine 6 (3), 77–83.
Magistretti, S., Dell'Era, C., Petruzzelli, A.M., 2019. How intelligent is Watson? Enabling digital transformation through artificial intelligence. Bus. Horiz. 62 (6), 819–829.
Massaro, M., Kim, S., 2022. Why is South Korea at the forefront of 5G? Insights from technology systems theory. Telecommun. Policy 46 (5), 102290. https://doi.org/10.1016/j.telpol.2021.102290.
Matinmikko, M., Latva-aho, M., Ahokangas, P., Seppänen, V., 2018. On regulations for 5G: Micro licensing for locally operated networks. Telecommun. Policy 42 (8), 622–635. https://doi.org/10.1016/j.telpol.2017.09.004.
Mendonça, S., Damásio, B., Charlita de Freitas, L., Oliveira, L., Cichy, M., Nicita, A., 2022. The rise of 5G technologies and systems: a quantitative analysis of knowledge production. Telecommun. Policy 46 (4), 102327. https://doi.org/10.1016/j.telpol.2022.102327.
Moqaddamerad, S., Tapinos, E., 2023. Managing business model innovation uncertainties in 5G technology: a future-oriented sensemaking perspective. R&D Manag. 53 (2), 244–259. https://doi.org/10.1111/radm.12559.
Naserian, E., Wang, X., Dahal, K.P., Alcaraz-Calero, J.M., Gao, H., 2021. A partition-based partial personalized model for points-of-interest recommendations. IEEE Transactions on Computational Social Systems 8 (5), 1223–1237. https://doi.org/10.1109/TCSS.2021.3064153.
Nenonen, S., Storbacka, K., Windahl, C., 2019. Capabilities for market-shaping: triggering and facilitating increased value creation. J. Acad. Mark. Sci. 47, 617–639.
Nikolic, I., Galli, N., 2022. Patent pools in 5G: the principles for facilitating pool licensing. Telecommun. Policy 46 (4), 102287. https://doi.org/10.1016/j.telpol.2021.102287.
Noh, H., Kim, K., Song, Y.-K., Lee, S., 2021. Opportunity-driven technology roadmapping: the case of 5G Mobile services. Technol. Forecast. Soc. Chang. 163, 120452. https://doi.org/10.1016/j.techfore.2020.120452.
Nyangaresi, V.O., Rodrigues, A.J., 2022. Efficient handover protocol for 5G and beyond networks. Comput. Secur. 113, 102546. https://doi.org/10.1016/j.cose.2021.102546.
Olokundun, M., Ogbari, M.E., Falola, H., Ibidunni, A.S., 2022. Leveraging 5G network for digital innovation in small and medium enterprises: a conceptual review. J. Innov. Entrep. 11 (1). https://doi.org/10.1186/s13731-021-00181-5.
Osterwalder, A., Pigneur, Y., Bernarda, G., Smith, A., 2014. Value Proposition Design: How to Create Products and Services Customers Want. John Wiley & Sons.
Oughton, E., Frias, Z., Russell, T., Sicker, D., Cleevely, D.D., 2018. Towards 5G: scenario-based assessment of the future supply and demand for mobile telecommunications infrastructure. Technol. Forecast. Soc. Chang. 133, 141–155. https://doi.org/10.1016/j.techfore.2018.03.016.
Pei, J., Li, S., Yu, Z., Ho, L., Liu, W., Wang, L., 2023. Federated learning encounters 6G wireless communication in the scenario of internet of things. IEEE Communications Standards Magazine 7 (1), 94–100.
Rathje, J.M., Katila, R., 2021. Enabling technologies and the role of private firms: a machine learning matching analysis. Strategy Science 6 (1), 5–21. https://doi.org/10.1287/stsc.2020.0112.
Rejeb, A., Rejeb, K., Treiblmaier, H., Appolloni, A., Alghamdi, S., Alhasawi, Y., Iranmanesh, M., 2023. The internet of things (IoT) in healthcare: taking stock and moving forward. Internet of Things 100721. https://doi.org/10.1016/j.iot.2023.100721.
Rendon Schneir, J., Bradford, J., Ajibulu, A., Pearson, K., Konstantinou, K., Osman, H., Zimmermann, G., 2022. A business case for 5G services in an industrial sea port area. Telecommun. Policy 46 (3), 102264. https://doi.org/10.1016/j.telpol.2021.102264.
Rotolo, D., Hicks, D., Martin, B.R., 2015. What is an emerging technology? Res. Policy 44 (10), 1827–1843.
Saadatmand, F., Lindgren, R., Schultze, U., 2019. Configurations of platform organizations: implications for complementor engagement. Res. Policy 48 (8), 103770.
Saraswat, D., Bhattacharya, P., Singh, A., Verma, A., Tanwar, S., Kumar, N., 2022. Secure 5G-assisted UAV access scheme in IoBT for region demarcation and surveillance operations. IEEE Communications Standards Magazine 6 (1), 58–66. https://doi.org/10.1109/MCOMSTD.0001.2100057.
Savunen, T., Hämmäinen, H., Kilkki, K., Kekolahti, P., 2023. The role of mobile network operators in next-generation public safety services. Telecommun. Policy 47 (3), 102489. https://doi.org/10.1016/j.telpol.2022.102489.
Schneir, J.R., Ajibulu, A., Konstantinou, K., Bradford, J., Zimmermann, G., Droste, H., Canto, R., 2019. A business case for 5G mobile broadband in a dense urban area. Telecommun. Policy 43 (7), 101813. https://doi.org/10.1016/j.telpol.2019.03.002.
Sjödin, D., Parida, V., Jovanovic, M., Visnjic, I., 2020. Value creation and value capture alignment in business model innovation: a process view on outcome-based business models. J. Prod. Innov. Manag. 37 (2), 158–183.
Tang, M., 2020. Huawei versus the United States? The geopolitics of exterritorial internet infrastructure. Int. J. Commun. 14, 22.
Teece, D.J., 2007. Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. Strateg. Manag. J. 28 (13), 1319–1350.
Teece, D.J., 2010. Business models, business strategy and innovation. Long Range Plan. 43 (2-3), 172–194.
Teece, D.J., 2018a. Profiting from innovation in the digital economy: enabling technologies, standards, and licensing models in the wireless world. Res. Policy 47 (8), 1367–1387. https://doi.org/10.1016/j.respol.2017.01.015.
Teece, D.J., 2018b. Business models and dynamic capabilities. Long Range Plan. 51 (1), 40–49.
Teece, D.J., 2021. Technological leadership and 5G patent portfolios: guiding strategic policy and licensing decisions. Calif. Manag. Rev. 63 (3), 5–34.
Tongur, S., Engwall, M., 2014. The business model dilemma of technology shifts. Technovation 34 (9), 525–535. https://doi.org/10.1016/j.technovation.2014.02.006.
Tranfeld, D., Denyer, D., Smart, P., 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. Br. J. Manag. 14, 207–222.
Vuojala, H., Mustonen, M., Chen, X., Kujanpää, K., Ruuska, P., Höyhtyä, M., Matinmikko-Blue, M., Kalliovaara, J., Talmola, P., Nyström, A.-G., 2020. Spectrum access options for vertical network service providers in 5G. Telecommun. Policy 44 (4), 101903. https://doi.org/10.1016/j.telpol.2019.101903.
Weick, K.E., Weick, K.E., 1995. Sensemaking in Organizations, Vol. 3. Sage Publications, Thousand Oaks, CA, pp. 1–231.
Weick, K.E., 1995. What theory is not, theorizing is. Adm. Sci. Q. 40 (3), 385–390.
Williams, L., Bergman, N., 2023. Koomey's law forevermore? A document analysis of the production and circulation of the promise of 'green 5G'. Technol. Forecast. Soc. Chang. 187, 122193. https://doi.org/10.1016/j.techfore.2022.122193.

Web references

European Commission (2023) https://digital-strategy.ec.europa.eu/en/policies/5g, last access 30.11.23.
ITU-R, 2015. IMT *Vision - framework and overall objectives of the future development of IMT for 2020 and beyond* ITU-R Report M.2083. International Telecommunications Union 11–12.
McKinsey & Company (2022). https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-is-5g, last access 30.11.23.

Mattia Magnaghi is a Ph.D. Candidate in Strategy and Innovation and a researcher at the "5G & Connected Digital Industry" applied research center at the Department of Management, Economics and Industrial Engineering – Politecnico di Milano. His research focuses on the strategic adoption of enabling technologies such as 5G technology focusing on firms' business model innovation mechanisms and ecosystem dynamics.

Antonio Ghezzi, Ph.D. is Associate Professor of Strategic Management and Entrepreneurship, and Head of the "Hi-tech Startups" and "Space Economy" applied research centers at the Department of Management, Economics and Industrial Engineering – Politecnico di Milano. His main research fields are Digital Strategy, Digital Transformation and Digital Entrepreneurship, with a focus on incumbents' and startups' business model design, innovation and validation, and the role of Lean Startup Approaches for experimentation. He is author of more than 250 scientific journal articles (appearing in outlets such as Technological Forecasting and Social Change, International Journal of Management Reviews, Journal of Business Research, Technovation, International Journal of Production Economics, British Journal of Management and Strategic Organization), books, book chapters and conference proceedings.

Andrea Rangone is a Full Professor of Entrepreneurship and Digital Business Innovation at Politecnico di Milano. He is the Co-founder of the Digital Innovation Observatory, a leading research center on business impact of digital technologies at Politecnico di Milano, and several digital startups; he is also co-founded, President and past CEO of Digital360, a demand generation, advisory and coaching company concerning digital business. His main research areas include digital transformation and the telco industry. He authored more than 100 national and international publications published in leading international journals such as Technological Forecasting and Social Change, Small Business Economics, Journal of Product and Innovation Management, and International Journal of Operations and Production Management.