A report for the Department for Digital, Culture, Media and Sport

Realising the Benefits of 5G

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clarity from complexity

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5G is the next generation technology standard for mobile internet

5G is the fifth and latest generation of mobile broadband internet, offering faster speeds, as well as higher capacity, lower latency, increased flexibility and increased reliability of connections. 5G can also connect a much larger number and variety of devices. In doing so, the expectation is that mobile telecoms companies will be able to address not only existing consumer and business mobile broadband customers, but also new markets (such as providing connectivity for low-latency Internet of Things (IoT) applications).

Superfast speeds are a key attraction for consumers

For individuals and households, greater capacity for the services they already use through faster mobile data connections could hold the biggest appeal in terms of migrating from 4G, to 5G, use. In the longer term, new use cases in the area of gaming, entertainment, smart health and retail are expected to emerge, as advanced features of 5G are deployed by MNOs and 5G devices become more pervasive.

The enhanced functionalities of 5G are expected to unlock new opportunities and business models

The 5G opportunity is perhaps more significant for enterprises, as the additional features of 5G are well suited for industrial applications. These features include low-latency, virtualised RAN; multi-access edge computing; and network slicing. 5G is also an enabling feature for other technology domains including robotics, IoT, and AR/VR. These enhanced functionalities of 5G are expected to unlock new business opportunities, new avenues of supply and demand for 5G services and significantly contribute to economic growth in the UK.

Households, media and entertainment and industrial IoT are expected to be early adopters

The enhanced functionalities of 5G will support several new or enhanced use cases. These include: virtual or augmented reality; ultra-high definition (UHD) video; robotics; connected autonomous vehicles; drones; remote machine manipulation; sensor networks; high-speed broadband; smart tracking; and IoT. There is an expectation that the media and entertainment sector and industrial IoT might be key areas of early adoption.

There are economic, social and environmental benefits of adopting 5G

The identification and conceptualisation of the benefits of 5G adoption is relatively well evidenced (but evolving, as new use cases emerge). However, the quantitative evidence of these benefits is limited. The benefits of 5G can be categorised as:

- Economic benefits – in the form of increased productivity to firms and additional GDP growth or, alternatively, in terms of cost reduction. These are realised through a wide range of mechanisms, including: reductions in factory downtime; lower defect rates in manufacturing; energy efficiency gains; and reduced waste. Other economic benefits are linked to the enabling effects of 5G: the creation of new business models and businesses or the launch of new products or services.
- Social benefits – including time savings linked to increased productivity in housekeeping and reduced travel times; and, from some 5G use cases, increased life expectancy, improved public safety, better health, reduced loneliness, and overall improvements in self-assessed quality of life and life satisfaction metrics.
- Environmental benefits – typically arising as a result of efficiency gains related to transport activities and the consumption of energy and natural resources; and so including reductions in traffic congestion and

greenhouse gas (GHG) emissions, reductions in the use of energy, and lower consumption of natural resources, such as water.

5G is being rolled out but the implementation of advanced functionalities will take time

5G networks are being expanded, largely on the basis of population density, to address a diverse range of users and uses. This is being supported by the government's 5G Test beds and Trials programme, which aims to accelerate the roll-out and use of 5G, and the recent widening of spectrum available for 5G. Even so, it takes time for new 3GPP-based functionalities to be integrated into networks and devices. The implementation of future 3GPP functionalities and the availability of reliant use cases will depend on demand and cost and likely be sporadic.

To date, most 5G has been deployed on non-standalone networks

To date, deployment of 5G by MNOs has been non-standalone rather than standalone. However, standalone networks, which operate independently of 4G, are important because they enable operators to offer more bespoke solutions, and furthermore many new features and functionalities will rely on the deployment of standalone networks. The pace of the transition to standalone networks will dictate when more advanced 5G applications become available.

There is a role, and support, for private networks

MNOs' slow implementation of the latest functionalities into public networks is stimulating demand for private 5G networks, while their longer transition to standalone presents an opportunity for private networks in the early delivery of some 5G features. Ofcom has taken steps to support the deployment of private 5G networks via shared use licences, and is making it easier for third parties to access spectrum from the national spectrum holdings of MNOs for local use.

5G readiness in the UK is reasonably high but users are unwilling to pay when the use cases and benefits are not clear

After the first 5G networks launched in the UK in 2019, 5G coverage in the UK was around 30% of the population as of Q4 2020, slightly above the European average of around 25%, based on analysis undertaken by Analysys Mason at that time, using data from the GSMA. Coverage has since expanded across further locations in the UK, with network speeds varying based on the deployment used by different operators in different locations. 5G readiness in the UK is reasonably high and the UK is a leader in the adoption of public cloud and AI.

Some wider digital barriers that may impede adoption of 5G in the UK include: alignment with global standards and spectrum arrangements and the impact of this on the wider 5G ecosystem; the absence of relevant skills and low levels of technology maturity; the availability and cost of spectrum; access to fibre backhaul. At the same time, the absence of a clear business case can undermine 5G coverage and available 5G functionalities, while demand from consumers may be slow to emerge until a live network demonstrates the functionalities and use cases, which requires costly and risky investment. Key barriers among users include an unwillingness to pay, especially when the use cases and benefits are not clear.

5G will bring incremental benefits over 4G but it could also have more transformative impacts

Incremental benefits of 5G over 4G include larger data transfers, the ability to maintain connections with very low latency, the ability to deliver contextual information in real time and the ability to connect many devices, and process and utilise data from those devices, in real time. 5G may also have more transformative impacts than previous mobile network technologies, through enabling other technological advances such as industrial AR/VR applications, robotics systems and cloud computing.

Modelling the impacts of 5G is subject to high levels of uncertainty

The absence of empirical data on how 5G is being used and by whom, limits the extent to which a model can be populated with data and parameters based on real world experience. This meant we had to rely on estimates and assumptions from historical studies of comparable technologies to develop some of the model parameters.

The strength of the model lies in comparing relative impacts across different market barrier levels

Considering the challenges to modelling 5G impacts, the model has been designed to break down the distribution of the benefits across consumer groups, households and firms, and geographical areas. The scale of the impacts of 5G are highly uncertain, but the likely relative impacts of 5G will be driven, to some extent, by the profile of 5G adoption. A further strength of the model lies in the functionality to change the profile of adoption according to different market barrier levels, to explore how these market barriers may affect both the scale and the distribution of the benefits.

We modelled the impacts of 5G adoption and market barriers for two scenarios

We modelled impacts of 5G adoption and demand-side market barriers for two scenarios:

- an optimistic view of 5G as a general-purpose technology (GPT) that could be adopted by nearly all firms, like the internet is currently;
- a more nuanced view of 5G in which adoption varies across consumer groups and firm sizes based on trends in uptake of advanced digital technologies (ADT)

The nature of 5G adoption is uncertain, and hence the impacts are uncertain too

The scenarios described above reflect differing opinions in the literature and industry of the nature of future 5G use and how widespread adoption will be. There is considerable uncertainty around which of these scenarios is more likely, and hence the potential size and scale of the impacts of 5G adoption. There is hence wide variation in the size of impacts between model scenarios and model results should be interpreted in the context of the scenario they correspond to.

UK economic benefits are projected at £41bn-£159bn cumulatively over 2021-35

UK economic benefits[1] are projected at £41bn-£159bn cumulatively over 2021-35 depending on the model scenario. Annual UK gross value added is projected to be 0.4%-1.6% higher in 2035 as a result of 5G technology (which is a relatively conservative estimate compared to the wider literature). Firms in the High-speed broadband to homes and offices consumer group and the Media and entertainment consumer group are projected to experience the largest impacts in proportional terms, though firms across a wide range of consumer groups are projected to benefit from 5G adoption.

5G adoption will positively impact GVA in all UK regions and countries

The largest impacts are estimated in London (£42bn in the GPT scenario and £12bn in the ADT scenario), the South East (£23bn in the GPT scenario and £5bn in the ADT scenario) and the South West (£15bn in the GPT scenario and £4bn in the ADT scenario). Urban areas within-each region and country are expected to benefit more strongly from 5G because it will be rolled out there first, and in the ADT scenario because faster adopting consumer groups are more highly concentrated in urban areas.

[1] Economic benefits are measured in terms of gross value added (GVA), which is defined as the value of output minus the value of intermediate consumption. This is of interest because GVA is the source of primary incomes in an economy; GVA is equal to the total remuneration to households (via salaries and wages) plus the total surplus of businesses (including profits) plus net taxes to government from production.

Private networks may be particularly important for rural areas

The model results indicate that private networks may be particularly important to rural areas if the slower roll-out of public networks in rural areas stimulates demand for private networks as an alternative. Furthermore, rural areas may also have a relatively high share of firms in consumer groups, such as Manufacturing, logistics and distribution and Energy and utilities, which favour the specific use cases for which private networks offer an advantage.

Environmental benefits range from 58-185 mtCO2e saved over 2021-35.

Environmental benefits modelled as avoided emissions are projected at ranging from 58-185 million tonnes of CO2 equivalent over 2021-35. Avoided emissions are greatest in consumer groups for which 5G improves transport efficiency or reduces travel, such as the Transport consumer group and the Retail and hospitality consumer group.

5G could save individuals £14.9-19.7bn over 2021-35

The literature review found multiple channels through which 5G will bring social benefits. However, limited evidence exists on the potential magnitude of most of these benefits. Therefore, modelling undertaken in this study was limited to estimating the value of time saved on housework and family care by individuals. The cumulative value of time saved over 2021-35 is projected to reach £14.9-19.7bn.

Removing market barriers could bring further economic, environmental and social benefits

Smart urban and Manufacturing, logistics and distribution stand to gain the most from lowering market barriers. £17bn-£58bn in additional GVA could be realised from reducing 5G market barriers in these two consumer groups alone (69-77% of total additional GVA benefits from lowering market barriers). Consumer groups for which business use cases were modelled are projected to realise relatively higher emissions savings as a result of removing market barriers, with the highest potential additional savings in Rural industries (73%), Manufacturing, logistics and distribution (41%), Smart urban (33%) and Energy and utilities (32%). Removing barriers to adoption of 5G could also potentially unlock £1.8-2.4bn of additional benefits to individuals.

1 Introduction

1.1 Background

The telecoms market is undergoing a transition to 5G networks and full-fibre broadband. 5G is expected to be a transformative technology that will create opportunities through new advanced use cases across sectors and markets for various consumer groups (e.g. households, enterprises, authorities etc. simply referred to as consumers henceforth).

5G is expected to significantly enhance digital connectivity in the UK, with initial 5G services launched by UK mobile network operators (MNOs) predominantly targeting individual consumers of mobile broadband (MBB) services. For these users, 5G radio means greater capacity for the services they already use on smartphones and other mobile devices. Beyond enhancing speeds and functionality of 4G, 5G standalone architecture is expected to unlock the more advanced technical functionalities of 5G, such as the ability to tailor quality of service through customised, end-to-end virtual network slices meeting new and different user requirements such as low-latency, ultra-reliable use cases.

These enhanced functionalities of 5G are expected to unlock new business opportunities, new avenues of supply and demand for 5G services and significantly contribute to economic growth in the UK (e.g. through increased productivity, new business models, new products and services, new markets and new use cases for various consumer groups).

In 2018, the UK government published the findings of its Future Telecoms Infrastructure Review (FTIR). The objective of the review was to support "large-scale commercial investment in the fixed and wireless networks that are vital for the UK to remain globally competitive in a digital world".

This vision forms a key aspect of the government's growth strategy, and is intended to ensure that the UK is at the forefront of the worldwide roll-out and take-up of high-speed connectivity services. Achieving this objective requires a strong market for 5G both on the demand-side and on the supply-side.

Against this background, the Department for Digital, Culture, Media & Sport (DCMS) has launched a pre-emptive review of 5G deployment and adoption in the UK. The objective is to understand the likely applications of 5G technology (use cases), the sectors that will benefit most from these capabilities, the barriers to take-up of 5G services, and an understanding of the overall economic impact generated by the success or failure of 5G roll-out in the UK.

While the market is expected to operate effectively to drive the delivery of 5G, there are various constraints that may impede this. For example, there are barriers to engagement on both demand and supply sides; divergence in incentives of suppliers and consumers; and complex transaction costs. These can result in sub-optimal outcomes for consumers, meaning the UK does not maximise the value of 5G.

In January 2021 DCMS appointed Cambridge Econometrics, Analysys Mason and Professor Ed Oughton to conduct analysis to help them better understand the demand side of the 5G market, the drivers and benefits of adoption, and the impact of barriers to adoption on the realisation of benefits. The work will assist in identifying areas in the market where there might be a need for government policy to support and promote the take up of 5G by users.

1.2 Aims of the project

In this context, this study seeks to provide a better understanding of the demand side of the 5G market, and the opportunities and challenges (barriers to adoption) various UK consumer groups of 5G will face. This project will provide an initial contribution to better understanding these areas which DCMS may seek to collect further evidence on as part of their ongoing research programme and internal evidence collection. The consumer groups represent related sectors of the economy and users of 5G within each of the consumer groups considered in this study are a mixture of individual consumers, households, businesses and the public sector (see section 3.3 for further discussion of this).

The key outputs of this study are UK-wide 5G adoption curves and a benefits model, which uses the adoption curves together with UK 5G geographic roll-out assumptions as its inputs to understand the potential scale of the benefits of 5G and the impact of removing barriers to adoption.

More specifically, this study has the following scope:

- Assessment of UK-wide 5G consumers (and consumer groups) and the 5G features that different consumer groups might use, informed by stakeholder interviews conducted as part of this study
- Identification and assessment of evidence underpinning the expected 5G benefits for UK consumers across the different consumer groups (e.g. businesses, households etc.) and development of a benefits model to quantify the benefits of 5G in the UK
- Identification and analysis of barriers and market failures that may prevent 5G consumers or consumer groups from getting the best and maximum value from 5G, also informed by stakeholder interviews

1.3 Stakeholder engagement

As part of the study, and to supplement the available literature on what use cases 5G might enable in the UK market, we conducted 16 one-to-one interviews with a range of 5G stakeholders. We also hosted a workshop via MS Teams, which was attended by more than 30 participants from 14 different organisations across the UK. The workshop and interviews focused on the topics of 5G demand, participants' outlook for 5G adoption – and the key consumer groups and potential use cases driving that – as well as any potential barriers and market failures to 5G adoption that they have experienced, or are aware of.

It is noted that we actively sought to interview stakeholders who were known to be actively considering 5G solutions (and/or companies either developing 5G products or deploying them), given the detailed nature of the questions being posed. Hence the stakeholder feedback will not be fully representative of all businesses within a 5G consumer group given there will be a wide variety of 5G awareness amongst businesses within specific groups. Given the commercial sensitivity of the information provided, the identity of all stakeholders engaged through the workshop and/or interviews, and any reference to them in the report, has been withheld. Nonetheless, the information provided fed into and helped shape the analysis.

1.4 Structure of this report

The report provides our assessment of 5G demand and market barriers for key consumer groups in the UK. It also provides an overview of our approach to modelling 5G impacts, scenario design and analysis of economic, environmental and social impacts projected using the model. The report is structured as follows:

- Chapter 2 provides an introduction to 5G to provide a high-level understanding on what 5G is and what it offers.
- Chapter 3 provides an overview of the main use cases and who the main consumer groups are expected to be, along with an overview of the main benefits of 5G.
- Chapter 4 provides an overview of recent developments in the evolution of the 5G market, to help understand the current state of development of the UK 5G market and how that is likely to change in future.
- Chapter 5 describes the key barriers that might affect 5G adoption across the consumer groups, and also how we might reflect the impact of these barriers within the adoption forecasts developed from the study.
- Chapter 6 describes our approach to modelling 5G adoption in the UK and estimating the economic, environmental, and social benefits.
- Chapter 7 describes the scenarios we have developed for the modelling.
- Chapter 8 presents and analyses the results from the scenario modelling.
- Chapter 9 concludes the report and summarises findings and insights.

2 Introducing 5G

In this chapter we provide an introduction to 5G to provide a high-level understanding what 5G is, the key features behind its potentially transformative impact, and how it compares to other connectivity technologies, such as 4G, wi-fi or fibre, and advanced technologies, such as the IoT or cloud computing.

2.1 What is 5G?

5G is the next generation technology standard for mobile internet

5G is the fifth and latest generation of mobile broadband internet. It is the successor to existing standards such as 3G and 4G. 5G is expected to significantly enhance digital connectivity in the UK, with initial 5G services launched by UK mobile network operators (MNOs) predominantly targeting individual consumers of mobile broadband (MBB) services.

2.2 What does 5G offer users?

5G networks offer several benefits beyond just faster speeds

5G networks will provide an increase in mobile speeds, as well as higher capacity, lower latency, increased flexibility and increased reliability of connections. 5G can also connect a much larger number and variety of devices. In so doing, the expectation is that mobile telecoms companies will be able to address not only existing consumer and business mobile broadband customers, but also new markets (such as providing connectivity for low-latency IoT applications).

Superfast speeds are a key attraction for consumers

For consumers, including individuals and households, 5G means greater capacity for the services they already use on smartphones and other mobile devices. 5G MBB therefore offers faster mobile data connections for video downloads, live streaming and gaming, offering a step change in quality of experience for these services compared to slower, 4G-based MBB.

In the longer term, more consumer use cases in the area of gaming (e.g. AR/VR gaming, cloud gaming), entertainment (e.g. 360-degree experiences, holographic events), smart health (e.g. wearables, remote health monitoring), retail (e.g. immersive shopping experiences, drone delivery) are expected to emerge as advanced features of 5G are deployed by MNOs and 5G devices, including but not limited to smartphones, become more pervasive.

The enhanced functionalities of 5G are expected to unlock new opportunities and business models

The 5G opportunity is perhaps more significant for enterprises, as the additional features of 5G are well suited for industrial applications:

- Low-latency, virtualised RAN: by changing the physical layer of radio frequencies, it is possible to transmit short packets of information with a very short delay, which, along with edge computing functionality (see below), enables very low latency connection such as needed for the real-time control of machinery or support for critical safety functions. With reduced signalling for short packets, the number of concurrent connections can also be increased to support many more devices, such as those envisaged as forming part of IoT.
- Multi-access edge computing: in the context of multi-access computing, it is possible to process data at the edge of the network, using virtualised platforms near to a company's premises. This reduces delay and allows for control and access to data without third-party involvement, which is

particularly important for analytics, where data needs to be processed quickly.

- Network slicing: communication paths can be allocated for the sole use of certain applications. The network is divided into a number of multiple virtual networks, all existing on a single infrastructure and each slice being configured to operate with specific quality-of-service (QoS). There is less cross-over between applications, more efficient use of resources and improved reliability and security.

5G is also an enabling feature to other technology domains (e.g. robotics, IoT, AR/VR), and is expected to catalyse further adoption of these adjacent technology both in the consumer and enterprise segments. For example:

- Robotics: low latency network feature enables a user to make real-time, precise actions based on the robot's surroundings from a remote environment.
- IoT: 5G brings about greater flexibility in terms of type of devices, and number of devices supported in the core network.
- Augmented reality (AR)/ virtual reality (VR): High bandwidth capabilities bring higher quality content which can be more realistic and immersive, while low latency enables content delivery with minimal delay for greater comfort.

These enhanced functionalities of 5G are expected to unlock new business opportunities, new avenues of supply and demand for 5G services and significantly contribute to economic growth in the UK (e.g. through increased productivity, new business models, new products and services, new markets and new use cases for various consumer groups).

It is very likely that once 5G networks are fully rolled out, a large part of the overall benefits of 5G to national economies will be generated by key consumer and enterprise use cases, through either economy-wide effects or significant productivity gains within economically important sectors. The most economically important sectors will vary across markets – however, the potential range of applications and sectors where 5G technology might play a role is significant.

A good source of case studies for the applications of 5G are reports on the UK's 5G Testbeds and Trials Programme. Table 2-1 below summarizes the findings for a selection of these reports, covering a variety of use cases.

Table 2-1: Summaries of case studies from the 5G Testbeds and Trials Programme

Author	Title	Summary
DCMS (2019)	5G Testbeds and Trials Programme	The paper provides some description of uptake in the case scenarios (consortia of over 70 organisations including over 40 SMEs). The paper also describes progress in the 6 key testbed areas: • **AutoAir** – a demonstration took place in Millbrook to "…help accelerate the development

		of the generation of connected and autonomous vehicles". • **5G Rural First** - 5GRF launched their Me+Moo app showcasing one of their agritech use cases. To date, they have had over 11,000 downloads on the app store. • **Worcestershire** – The testbed has reportedly "…help[ed] factories make significant efficiency gains." • **5G Smart Tourism** – Demonstrations of VR and tourism took place (e.g. Roman Baths, Bristol). • **5GRIT** - Within the rural broadband space, their service has shown that 5G can deliver 30Mbps broadband to remote rural areas. • **Liverpool 5G Testbed** - The new technology has also improved the quality of life for people managing long term health conditions.
Liverpool 5G Health and Social Care Testbed (2019)	Benefits, Outcomes and Impact: Final analysis of combined data from use cases	This paper analyses and presents evidence relating to the economic and social impacts of the Liverpool Health and Social Care testbed. • Cumulatively, it estimated that the combined cost-savings for health and social care services across various 5G applications amounted to £247,688 per hundred users per year. • Social impacts are also found in terms of reported life satisfaction and sense of inclusion among users.
Sainani and Lees (2019)	5G Rural Integrated Testbed: Final Report – Tourism Apps	This paper analyses and presents evidence from the 5GRIT testbed relating to the economic impacts of tourism apps, including an established AR application called World Around Me (WAM) used to deliver video streaming of heritage content over 5G. The paper establishes a direct relationship between WAM usage in the region and its economic benefits. • WAM was used by 89 users who searched 1712 times and spent 18hrs 12 mins in WAM. • Based on this, the paper estimates that around £17,120 was brought into the region through these WAM users (£10 per use). • If WAM were promoted to 10,000 people, who use WAM about 200,000 times, this would bring an economic benefit of £2 million to the region.
Leese (2019a)	5G Rural Integrated Testbed: Final Report – Arable Use Cases	This paper analyses and presents evidence from the 5GRIT testbed relating to the economic impacts of 5G applications on arable land yield. The paper considers the application of 5G in enabling unmanned aerial vehicles (UAV) to collect multi-spectral images of arable land. This enables farmers to manage inputs (most importantly fertiliser).

		These applications are found to increase average farm wheat yields from 10.4 to 11.7 tonnes per hectare. Based on a wheat price of £50 per tonne, this equates to £195 per hectare in increased revenue (approx.. £2395 per typical farm). Ways in which these technologies might become commercially viable are also explored and yardstick goals for impacts on animal health is hypothesised.
Bruce (2019)	5G Rural Integrated Testbed: Final Report – Livestock and UAV	The paper describes testbed results including cost savings for average sheep farms (fewer callouts and medical bills). Consultations with farmers who were involved in the testbed were key to the research method. The paper estimated that: • a 5% reduction can be achieved through UAV applications, resulting in a cost saving of £0.34 pence per animal on veterinary products; • on a farm with 895 sheep (average size), this would equate to £0.34x895=£304 per year; • 1 call per year could be saved as a result of monitoring the animals more closely; • This equates to a saving of £50-£90 p.a. based on the current cost of a vet call out on these farms. • Overall, both savings could amount to £350 - £390 per year on the average sheep farm.

2.3 Key features behind the transformative impact of 5G

The virtualisation of 5G networks is expected to drive the most transformative aspects of 5G

It is the virtualisation and cloud-based transformation of 5G core networks that is expected to drive the most transformative aspects of 5G, potentially leading to the greatest benefits across industrial and enterprise 5G users. This virtualisation of 5G architecture follows the broader trends of software-defined capabilities and cloud-based storage and implementation that is at the heart of industrial digital transformation programmes in the UK and worldwide.

Key benefits include greater flexibility, scalability and the decoupling of applications from hardware

Virtualisation refers to the core networks of 5G being implemented in software, rather than in hardware. Additionally, virtualisation of parts of the radio access network (RAN) is occurring through virtual RAN solutions. Open RAN is one example of a virtual RAN implementation. Key benefits of virtualised, cloud-based approaches to 5G implementation include greater flexibility, scalability and decoupling of applications from hardware. Another benefit is that a move away from hardware-based implementation can potentially create opportunities for alternative software-based vendors to provide some or all of 5G end-to-end solutions, improving supplier diversity.

But current virtualised 5G core solutions are not 'cloud-native'

However, whilst virtualised 5G core network infrastructure solutions available in the market, early versions were not 'cloud-native'. The first set of 5G standards were completed as rapidly as possible to enable MNOs who wished to do so to roll out 5G quickly, and so the initial standards do not define the full 5G solutions. Initial 5G implementations in the UK used existing 4G core networks to support 5G plus 4G connectivity although operators are now moving to deploy cloud-native, container-based 5G packet core infrastructure, which can be used to control 4G/5G 'non-standalone' radio networks, plus 5G standalone services. Early implementations of 5G virtualised core networks have also progressed in the private 5G market. Many 5G equipment vendors are involved in multiple proof-of-concept and testbed programmes in the UK and around the world demonstrating how 5G core network platforms are evolving. Most often, early proof of concept is specific to individual use cases, and may not be aligned with the vision of 5G offering multiple end-to-end slices simultaneously able to meet different user requirements.

Many advanced 5G capabilities rely on virtualised architectures being implemented

Virtualisation and 'cloudification' (making virtual 5G core networks compatible with cloud implementations) is important because many of the advanced capabilities that are captured in the 5G vision (including ultra-low latency and dynamic end-to-end slicing) rely on virtualised architectures being implemented. 5G SA architectures also promise to transform the total cost of ownership by reducing the cost of deploying large hardware solutions. Conversely, the transition from 5G non-standalone (NSA) to 5G SA raises several complexities and requires significant support from equipment vendors through implementation contracts. Hence the cost and complexity of this transition may affect the timelines for these changes being made. A further risk for MNOs is that current 5G core solutions are immature and not yet proven for large-scale roll-outs. This means that timelines to deploy 5G core networks have become misaligned with those to deploy 5G radio, since MNOs have proceeded with deploying 5G radio, but without the corresponding 5G core networks. This immaturity in 5G core solutions for large-scale roll-outs is also one reason why it appears that MNOs have started to deliver 5G services to industrial and enterprise users via private 5G networks, using shared-access spectrum in the 3.8-4.2GHz band together with separate on-site core networks serving specific customers. The evolution path from these disparate networks towards fully cloud-native, end-to-end 5G networks being deployed nationwide is not yet clear. Several of the barriers to deployment presented later in this report stem from the uncertainty concerning this migration towards end-to-end virtualised capability.

2.4 How 5G will compare with other connectivity technologies

The usefulness of 5G to businesses that have invested in existing technologies will vary

It is noted that some early adopters of 5G will previously have used 4G connectivity, and some 5G users have and may continue to use Wi-Fi and other short-range wireless technologies for some of the use cases that 5G will support. Many businesses in the UK already rely on fixed broadband to provide their main business connectivity. The Government's full-fibre initiatives include a recent £5bn 'Project Gigabit' to target hard to reach homes and businesses with next generation (fixed) broadband infrastructure. What 5G offers for businesses that have invested in existing technologies will vary depending on the nature of each business and the individual requirements that businesses have.

5G is being rolled out as existing connectivity technologies expand their capabilities

Some potential UK 5G have made substantial investments to optimise existing connectivity solutions for their specific deployment and usage needs, included fibre broadband, and wireless solutions, including Wi-Fi, public and private 4G deployments. The roll-out of 5G is taking place at the same time as existing wireless and fixed connectivity technologies (e.g. 4G, Wi-Fi, Fibre) are expanding their capabilities (Figure 2-1). There are a wide range of existing low power wireless solutions ('short range devices', or SRD) used in the UK market and elsewhere for asset tracking, wireless sensing radio frequency identification (RFID), and other uses. These short-range devices use spectrum designed for SRD use, which is typically harmonised across Europe for such purposes. Spectrum bands used for these purposes include the 2.4GHz band, widely used around the world not only for Wi-Fi but also for a range of other short-range, low power wireless connections (Bluetooth, zigbee, etc.).

Investment in 5G is taking place in the UK at the same time as significant investment is being made into full-fibre implementation across the country. Competition is driving local investment in fibre with several firms creating alternative fibre infrastructures in the UK in competition with the incumbent provider, Openreach. As evidenced by other published literature, 5G and fibre together are expected to benefit individuals, businesses, Governments and wider society through enabling increases in broadband speeds (Oxera for the Broadband Stakeholder Group, 2019).

Figure 2-1: Existing connectivity technologies which are expanding their capabilities

4G*	High speed mobile broadband, with the capacity provided varying depending on spectrum used and density of infrastructure, together with 3GPP version (LTE/LTE-A)
Wi-Fi 6	Wi-Fi 6 is the next generation of Wi-Fi technology with improved speed and features to improve device efficiency, although with performance dependent on spectrum used
Fibre	Offers highest speed, low latency fixed connections into homes and offices, and also plays a role in mobile networks via offering high capacity fibre backhaul
LPWAN (NB-IoT, LoRa, etc.)	Low power and lower bit technologies that support high densities of connected devices, typically at lower bit rates
Short-range wireless (including dedicated short-range communications (DSRC), RFID etc).	A range of proprietary short-range wireless technologies providing device to device connectivity, which includes DSRC, also referred to as IEEE802.11p, which is designed to use the 5.9GHz band for vehicle to vehicle / vehicle to roadside connectivity (V2V and V2I)

*Deployed in multiple frequency bands in the UK with different bandwidths/range – 4G low bands (800/900MHz) provide coverage but limited capacity, whereas 4G mid-bands (1800MHz and 2100MHz) provide greater capacity. 2300MHz and 2600MHz bands are also used for 4G (2300MHz is only available to one UK MNO), offering high capacity. Some capacity in 900MHz, 1800MHz and 2100MHz is also used for legacy 2G/3G connectivity currently.

Source: Analysys Mason.

5G and fibre are complementary technologies…

5G and fibre investment can be viewed as complementary in that 5G infrastructures will utilise fibre networks for backhaul purposes where available.

…as are 5G radio and Wi-Fi

As well as being overlaid onto 4G networks by MNOs to provide wide-area coverage and mobility, 5G radio can also be deployed to provide localised coverage (either outdoors, or indoors) to deliver use cases similar to those provided by existing short-range wireless solutions such as Wi-Fi or other proprietary short-range wireless technologies. These localised areas could be indoors or outdoors (e.g. within an indoor business or factory setting, outdoors in a factory yard or across an industrial campus).

Short-range wireless solutions such as Wi-Fi are limited to localised coverage due to the stipulation of low transmit power and other restrictions placed on use of licence exempt spectrum that these technologies use in the 2.4GHz or 5GHz band.

Existing Wi-Fi solutions are evolving currently with definition of a new 'Wi-Fi 6' specification. The consumer group, Which, have published a useful guide on Wi-Fi-6[2].

5G and Wi-Fi both provide high data rates to support wireless data applications, and the two technologies can co-exist together in several environments (typical environments in which both 5G and Wi-Fi might be used include in the home, in the office, while driving, or working remotely). There are several key differences between the two technologies however, which are summarised below:

- 5G technologies are standardised internationally by the Third Generation Partnership Project (3GPP), which is a global standardisation group formed of several regional standardisation bodies (such as the European Telecommunications Standards Institute), and involving stakeholders across the mobile industry, including large global mobile equipment vendors and mobile operators. Wi-Fi is standardised by the IEEE, an international standards organisation traditionally involving IT equipment vendors.
- Wi-Fi operates around the world using two spectrum bands, at 2.4GHz and at 5GHz. In many markets, including Europe, additional spectrum in the lower 6GHz band is being made available to give further capacity for Wi-Fi use. Several markets (e.g. USA, Brazil, Saudi Arabia) have made further spectrum available in the upper 6GHz band. In Europe, future use of this upper 6GHz spectrum was under discussion at the time of producing this report (as part of preparations for the ITU World Radiocommunication Conference in 2023). Spectrum used for Wi-Fi is available on a licence-exempt basis in most markets. This means that equipment can be installed without individual licences being needed, provided the equipment complies with the technical conditions for use of the 2.5GHz and 5GHz bands. These technical conditions are designed to enable co-existence between the different Wi-Fi systems that share the same 2.4GHz and/or 5GHz bandwidth. Technical conditions include limits on transmitted power and limits on the types of antenna that can be attached to a Wi-Fi system. As such, Wi-Fi is a popular choice to provide localised coverage (e.g. inside a

[2] https://www.which.co.uk/reviews/wi-fi-routers-and-extenders/article/what-is-wi-fi-6-agTTG2Y9Jeni

home or an office), where power and coverage limitations do not inhibit use.

- Wi-Fi is currently a popular choice for indoor wireless networks and will continue to be used in this environment. Wi-Fi is not typically deployed outdoors, although some outdoor deployments do exist. Whilst 5G deployment is taking place using outdoor base stations currently, it is envisaged that some 5G deployment will be indoors (e.g. using 3.5GHz or 26GHz small cells). Within the indoor environment therefore, 5G is likely to be an alternative to deploying Wi-Fi. Conversely, where some users have already invested in large-scale indoor Wi-Fi coverage, those users seem unlikely to replace this Wi-Fi coverage with 5G for areas where Wi-Fi already covers in the short term.
- Where 5G and Wi-Fi networks potentially compete is therefore largely in the indoor environment, where businesses who have invested in Wi-Fi coverage might question the need for 5G. In the current market, a hybrid model often applies to provide coverage to larger outdoor/indoor environments such as campuses, stadiums and rail stations. This hybrid model is enabled through consumer devices (smartphones, tablets etc) having both cellular and Wi-Fi capabilities. Users who subscribe to a 4G mobile network but also use a Wi-Fi-enabled device can therefore choose which capability to use in different locations and circumstances. What is likely to change in the 5G era is that the amount of data being transferred will be considerably higher. This surge in data use is likely to lead to a reduction in user experience and use case capabilities if relying on Wi-Fi technology, given that the capacity of Wi-Fi is fixed (based on the amount of spectrum available, which is also shared across the entire Wi-Fi market). What 5G promises to deliver over and above Wi-Fi in environments such as stadiums, indoor enterprise or industrial settings, is very high capacity (both for downlinks and uplinks) to address very large amounts of data. It is also possible that 5G deployment might better address some types of indoor use (such as covering a building with several floors, for example).
- In summary, both Wi-Fi 6 and 5G will offer improved user experience through lower latency and higher bandwidth compared to the respective previous generations of those technologies (i.e. Wi-Fi 6 provides performance improvements over previous generations of Wi-Fi technology and 5G provides improvements over 3G/4G).
- 5G, however is expected to differentiate itself from Wi-Fi 6 (as 4G does over existing Wi-Fi solutions) by providing wide-area mobility with longer network ranges as well as native core / network slice integration capabilities.

4G and 5G will complement each other in the short term

Similarly, 4G and 5G are expected to act as complementary technologies in the short term as operators continue to expand 5G networks and rely on current 4G coverage, with more immediate use cases largely focused on providing 5G-based mobile broadband to individual consumers and businesses. According to GSMA’s ‘The Mobile Economy 2020’ report (2020), 4G connections accounted for 52% of mobile connections worldwide in 2019 and is still expected to see some further growth in the next five years. It is evident however, that some of the more transformative benefits of 5G, compared to previous mobile technologies, are still some years away and are dependent on the full portfolio of 5G spectrum bands (medium and high frequencies) and virtualisation of the 5G core (see Figure 2-2).

Figure 2-2: Transformative benefits of 5G enabled through in mid- and high-band frequencies together with virtualisation of the 5G core

5G mid band (3.5GHz) / 5G high band (26GHz)	Ultra-fast, low latency*, mobile connectivity, which, together with 5G core networks (inc. cloud-based) and edge cloud, enables end-to-end, dynamic slicing
5G low band (700MHz)	Higher-speed, lower latency overlay to 4G (but without mid band/high band and 5G core, is unlikely to deliver high capacity or end-to-end slicing on its own)
5G using existing mobile bands	Re-farming of existing spectrum from 3G/4G use to 5G, which is also enabled through various technology solutions offered by major vendors (such as Ericsson spectrum sharing, enabling an MNO to share spectrum within its network between 4G and 5G traffic)
Edge computing and Cloud computing	▪ Cloud refers to on-demand IT services used by enterprises and businesses delivered over the internet ▪ Edge computing helps remove latency limitations between networks and devices ▪ 5G core network refers to virtualising the core network topology – cloud-native refers to taking this topology into the cloud

Note: * Depending on deployment used

Source: Analysys Mason.

The benefits of 5G compared to 4G

The capabilities of 5G compared to 4G are discussed extensively in published reports. Some of the reported benefits of 5G as compared to 4G ((GSMA 2020), (5G.co.uk 2020), (Analysys Mason 2018)) are outlined below:

- 5G may enable a large amount of spectrum to be aggregated – even across different frequency bands – to achieve higher peak/average speeds (both uplink and downlink)
- 5G.co.uk (5G.co.uk 2020) reported that 4G real-world download speeds averaged 20-30Mbit/s, where 5G real world speeds sat at 150Mbit/s-1Gbit/s.[3] However, the expectation is that 5G speeds could increase to 10Gbit/s (>1000x greater than that achieved by 4G) as stand-alone networks develop
- In addition to higher speeds, 5G is expected to provide much improved latency when compared to 4G, i.e. 21-26ms versus 50ms. Theoretically, 5G latency could reach 1ms, however, substantial networks enhancements will be required before that is achieved
- 5G is expected to make use of associated technologies (e.g. mobile edge-cloud, AI, small cells) for the development of agile and dynamic networks,

[3] Opensignal report (Opensignal 2019) found that the top 5G speed reached by any MNO network in the UK was 599Mbit/s (between April-September 2019).

providing superior speeds, latency and coverage required for use cases enabled by 5G. (see standalone Appendix A for a full list of 5G use cases)

- In previous cellular network evolutions, 4G was noted for providing significant speed improvements compared to 3G for mobile data use. As well as providing further improvements in speeds compared to 4G, 5G is also expected to facilitate the emergence of new use cases, not currently possible through other mobile technologies. (see standalone Appendix A for a full list of 5G use cases)
- Network slicing capabilities (born through 5G networks) will support the provision of end-to-end dedicated capacity and tailored uplink/download speeds
- Currently, 4G offers superior coverage to 5G as continue to expand 5G networks. The aim however, is for 5G networks to dynamically provide the 'perception' of ubiquitous coverage by predicting user capacity requirements and movements, thus providing seamless and sufficient network availability

The benefits of 5G extend beyond just faster speeds, but are less well understood

In summary, the speed improvements from 5G versus 4G appears to be well documented, however, some published documents (including from the mobile industry itself) indicate that other benefits of 5G might be less well understood currently. The GSMA for example refers to the benefits of 5G for enterprises not being realised until 5G stand-alone deployments are available. The GSMA refers to the benefits of capabilities such as network slicing, edge computing and low latency services taking time to penetrate the market, resulting in a risk that some users believe that 4G remains 'good enough' (GSMA 2020).

It is clear that current 5G services will evolve as MNOs continue to upgrade their networks. These further infrastructure upgrades and network functionality investments and enhancements will be required for full 5G benefits (e.g. arising from superior latency performance, bespoke network slices and edge computing) to be demonstrated.

2.5 5G may be complementary or synergistic to other advanced technologies

Five types of advanced technologies that enable or benefit from 5G services

The timing of 5G adoption may be complementary or synergistic to the emergence or maturation of other advanced technologies. There are five key types of associated technologies that either enable or benefit from 5G services and building up these technologies is important for 5G success, both from a capability and ecosystem perspective – namely, IoT, cloud computing, AI, XR and automation and robotics. 5G characteristics and capabilities (including those that are still expected to emerge through future 3GPP releases and network investments) are likely to enhance the experience of these advanced technologies. Additionally, experience may also be enhanced through the improved connectivity service that 5G provides over other connectivity technologies (e.g. 4G and Wi-Fi). This improvement in connectivity and service from 5G (e.g. lower latency, higher bandwidth and improved mobility when compared to Wi-Fi) may provide impetus for adoption of advanced technologies and associated use cases. Summaries of 5G-associated advanced technologies are included below:

IoT (IoT)

- 5G enhances communication functionality for IoT connectivity and brings about greater flexibility in terms of type of devices, and number of devices supported in the core network (with 5G IoT capabilities being referred to as massive machine-type connections, or mMTC). However, in parallel to 5G-based mMTC being specified, 4G-based IoT solutions are still evolving and being deployed.
    - NB-IoT is an LTE-based technology used for low power wide area applications like cameras traffic lights and environmental sensors, according to Vodafone's website[4].
    - LTE-M is also an LTE-based IoT technology providing higher-bandwidth IoT applications compared to NB-IoT. Telefonica's website refers to LTE-M providing asset tracking, utilities monitoring and assisted living and smart city applications[5].
    - NR-Light is a 3GPP Release 17 capability aimed at developing a new 5G IoT device type meant to provide lower complexity and reduced energy consumption compared to previous generations of cellular IoT such as NB-IoT and LTE-M.

Cloud computing

- Edge computing enables low latency 5G applications by bringing computing capabilities closer to the application.
    - XR (eXtended reality, including augmented reality (AR), virtual reality (VR) and mixed reality (MR)) and audio visual devices can offload their computing resources to the edge network without suffering latency issues such that cost can be kept low and devices can be miniaturised.
    - Remote control in machinery, vehicles, drones can be carried out with low latency for precise movements.

Artificial Intelligence (AI)

- 5G enables the proliferation of sensors and faster data transfer, enabling the collection and processing of increasing amounts of data. Better data inputs result in better AI models.
- AI is important to 5G as it helps to make sense of the large volume of data to derive actionable insights.
- AI can play a role in managing 5G networks through software.

eXtended reality (XR) – Augmented, virtual and mixed reality

- High bandwidth capabilities bring better quality content to XR applications for a more realistic and immersive experience (e.g. high definition (HD)/4K content streaming to XR headsets).
- Low latency capabilities enable content to be delivered with minimal delay for a more comfortable user experience.

[4] https://publicsector.vodafone.co.uk/services/vodafone-narrow-band-iot/

[5] https://www.o2.co.uk/business/solutions/iot/lte-m

- XR adoption has not taken off as expected and the benefits promised by 5G could potentially move the needle and catalyse mainstream adoption.

Automation and robotics (including drones)

- There are two main types of automation and robotics applications:
  - remote control where the application is being controlled by an operator in a separate location (e.g. control room/head office);
  - autonomous where the application is being powered by an AI algorithm and carry out tasks without need for human intervention.
- Remote control: low latency network feature enables a central control room to be able to make real-time, precise actions based on the robot's surroundings. This can be applied to vehicles, construction machinery, plant equipment where real-time actions are critical to ensure safety.
- Autonomous: low latency and edge computing helps the robots/drones make fast autonomous decisions such that timely responses can be made to ensure safety.
- Network slicing is critical to robotics applications as network QoS can be guaranteed for effective and safe application.

Whilst it is understood that 5G-associated advanced technologies are likely to enable or benefit from 5G services, it is clear that the emergence, development and maturity of these advanced technologies are dependent on an entire supply-chain to support them. This includes fully-deployed and capable networks with sufficient coverage, as well as available and maturing ecosystems providing productised and affordable devices with shorter lead times.

3 Applications and benefits of 5G

This chapter provides an overview of the main ways in which 5G is expected to be applied (the use cases) and who the main consumer groups are expected to be. There then follows a summary of the benefits that are expected to be derived from the exploitation of 5G across different consumer groups.

3.1 5G consumer groups, sectors and use cases

Using evidence gathered from published literature, together with reports of use cases being tested in the 5GTT programme, a list of 5G use cases was developed for discussion with DCMS.

These cases were identified based on what has been presented in published literature as being 5G-enabled use cases (i.e. benefitting from full capabilities of 5G, such as use cases needing very high capacity, machine-type connections, low latency and/or high reliability, and/or use cases where 5G provides an improvement compared to existing solutions e.g. higher capacity for eMBB, relative to 4G). The identified list of use cases was corroborated through discussion with the DCMS team, along with the stakeholder workshop and one-to-one stakeholder interviews conducted for this study (see Section 1.3). It is noted that within the scope of the study, it was not possible to conduct one-to-one interviews with stakeholders from all of the identified 5G consumer groups.

Nine 5G consumer groups are identified

We then identified what sectors of the market will use the different use cases, and we organised user sectors into nine key groups. Each of our nine '5G consumer groups' represents several sectors of potential 5G users. For each sector of use, there are multiple 5G use cases (or applications) that are widely discussed in the literature we have reviewed.

Consumer groups and sectors are shown in Table 3-1. Consumer groups therefore represent related sectors of the economy e.g. the public services consumer group represents all public sector uses of 5G.

Each consumer group consists of a mixture of individual consumers, private firms and the public sector, all of whom might be consumers of 5G. This is further discussed in Section 3.3.

Table 3-1: Summary of consumer groups and sectors

	Consumer group	Sector	
1	Media and entertainment	1a	Gaming
		1b	Media
		1c	Venues and events
2	Public services	2a	Health and social care
		2b	Education
		2c	Public safety and security
3	Energy and utilities	3a	Utilities
		3b	Oil and gas
		3c	Mining
		3d	Renewables

4	Rural industries	4a	Agriculture
		4b	Forestry
		4c	Fishing
		4d	Tourism
5	Smart urban	5a	Smart cities
		5b	Construction
		5c	Professional services
		5d	Tourism
6	Transport	6a	Public transport
		6b	Automotive
		6c	Airports
		6d	Water transport
7	Manufacturing, logistics and distribution	7a	Freight
		7b	Ports
		7c	Smart factories
8	High-speed broadband into homes and offices	8a	Homes
		8b	Offices
9	Retail and hospitality	9a	E-commerce
		9b	Hospitality

Source: Analysys Mason.

Existing technologies can already support some 5G use cases but 5G may enable new use cases that existing technologies cannot support

An issue to consider when assessing demand for 5G services, and subsequently the benefits of 5G, is that some potential 5G users might already use existing wireless technologies to address some of the use cases identified below. However, our assumption is that 5G infrastructure will provide enhanced performance for these use cases, compared to using earlier cellular technology (i.e. given that 5G infrastructure will offer higher capacity and higher peak speeds, lower latency and higher reliability). New 5G architecture will enable network functions to be handled in software, which will also enable new uses, and enhance existing ones, by enabling effective processing (and AI-type analysis) of large volumes of data, for example. In addition, 5G will introduce the definition and orchestration of network slices, to allocate network resources dynamically and in a quality-managed way to different users and applications. As such, 5G infrastructure might also enable entirely new use cases that are not possible using today's wireless infrastructure.

New or enhanced applications enabled by 5G

In our analysis we have sought to identify the capabilities of 5G which, compared to previous generations of mobile technology, enable enhanced or new uses that are expected to underpin 5G demand and adoption. We have referred to these capabilities as 5G-enabled applications or '5G applications', as described in Table 3-2.

Table 3-2: Description of 5G applications

5G applications	Description
VR/AR	Real-time, high-speed, low-latency and managed QoS connectivity for VR/AR
UHD video	Real-time, high-speed, low-latency support for UHD video
Robotics	Real-time, mission-critical, high-speed, ultra low-latency and managed QoS connectivity for robotics

Autonomous/connected vehicles	Real-time, high-speed, ultra low-latency wide-area and managed QoS connectivity for autonomous vehicles
Drones	Real-time, low-latency, wide-area 5G connectivity for drones
Remote object/machine manipulation	Real-time, mission-critical, high-speed, ultra low-latency and managed QoS connectivity for remote object and machine manipulation
Sensor networks	Real-time, high-density, wide-area connectivity for sensor network collation and data mining
High-speed broadband	High-speed wireless broadband connectivity to homes and offices
Smart tracking	Real-time, wide-area 5G connectivity for smart tracking

Source: Analysys Mason.

A summary of key 5G applications per consumer group are presented in Table 3-3.

Table 3-3: Key 5G applications per consumer group

	1	2	3	4	5	6	7	8	9
	Media and Entertainment	Public services	Energy and Utilities	Rural industries	Smart urban	Transport	Manufacturing logistics and distribution	High speed broadband into homes and offices	Retail and Hospitality
VR/AR	✓	✓	✓	✓					✓
UHD video	✓	✓			✓	✓		✓	✓
Robotics			✓		✓		✓		
Drones					✓	✓	✓		
Remote object/machine manipulation				✓			✓		
Sensor networks			✓	✓	✓		✓		
High-speed broadband		✓	✓	✓	✓	✓	✓		✓
Smart tracking	✓	✓		✓	✓	✓		✓	✓
Autonomous/connected vehicles				✓		✓	✓		

Source: Analysys Mason.

3.2 Evidence on 5G use cases and consumer groups

This section provides a discussion on 5G demand, use cases and relevant consumer groups.

Mobile broadband demand is driving initial deployment by MNOs as they do not understand other use cases

We found that initial deployment is being driven by a need to provide additional capacity for MBB consumers. Other uses of 5G such as industrial, transport, healthcare etc. are not widely served yet by public networks, although several trials are being conducted in specific sectors (ports, manufacturing, utilities), with a view to furthering the understanding of how 5G might be deployed to meet these different requirements.

We identified four key early adopters of 5G:

Evidence identifies four key early adopters of 5G

- individual consumers;
- media and entertainment;
- broadband; and,
- industrial IoT.

Individual consumers were identified as obvious early adopters of 5G, driven by eMBB focus from MNOs and new 5G handsets coming to market. Use cases linked to eMBB capabilities include temporary mobile sites, improved video download speeds (including UHD) and AR/VR. Other early adopters include media and entertainment, and broadband in homes and offices (e.g. FWA, eMBB connectivity). Industrial IoT is also highlighted as an earlier use case of 5G when applied to manufacturing, energy and utilities, smart urban and transport. Use cases dependent on later 3GPP releases (16/17), or those demanding ultra-low latency, mission critical connectivity (automation, robotics, AR/VR in surgeries etc.) using nationwide 5G networks will largely depend on further investment being made to add these capabilities, which may emerge at a later stage.

Table 3-4: Use cases relevant to different consumer groups

Consumer group	Use cases
Media and entertainment	UHD video consumption; content production; immersive and location-based digital experiences (e.g. interactive concerts, holographic streaming and enhanced football games); live media streaming
Public services	Temporary/mobile eMBB connectivity (e.g. vaccination sites); mobility for public service workers; IoT deployments for remote patient monitoring and predictions; ultra-reliable, ultra-low latency uses cases such as AR/VR and robotics for training and surgery (longer-term)
Energy and utilities	Large scale IoT deployment for utility networks; AR/VR for underground network mapping; UHD off-site communications and training; drones to analyse resource sites (e.g. quarries, mines, reservoirs)
Rural industries	Rural MBB connectivity to consumers and businesses; immersive, virtual experiences for tourism; IoT deployments for environmental monitoring
Smart urban	The use cases within smart urban are diverse but might include video surveillance (CCTV); large scale IoT and high density sensor networks; construction; traffic management; immersive, virtual experiences for tourism, leisure and retail; large events (immersive experiences at stadiums)
Transport	Roadside small cell deployments for connected cars; connected vehicles (V2X); offloading flight data at terminals (e.g. Passenger data); ultra-low latency and reliable

	connectivity for public transport signalling or radio systems; real-time video for driverless transport vehicles (long-term)
Manufacturing, logistics and distribution	End-to-end integration of solutions; outdoor connectivity (where Wi-Fi or 4G may be unsuitable); machine mobility (wireless factory floors); smart tracking; sensor networks and datamining (e.g. geolocation, motion sensors, measurements, predictive maintenance); supply-chain, asset and capacity management; AR/VR for remote maintenance and remote control; image processing for remote quality control and product life cycle; automated guided vehicles; automated machinery/robotics (e.g. semi-nomadic cranes, automated process machinery)
Broadband into homes and offices	eMBB connectivity (mobile or FWA); remote working; mobility for users; UHD video; AR/VR
Retail and hospitality	The use cases within retail and hospitality are diverse and might overlap with some of those identified above (e.g. in the smart urban consumer group) – for example, mixed reality e-commerce (e.g. shopping online at a fashion event); content creation for advertising; augmented shopping experiences.

Source: Analysys Mason.

Many potential users are at very early stages of adoption, with deployment some way off

Many industrially-focused users (energy and utilities, manufacturing, transport) that have started looking at these 5G use cases, or have received funding for 5G trials, appear to be at very early stages of 5G adoption, with proof of concepts (PoC) still being developed or tested in lab environments before they are deployed in real world situations. These PoC can take some time to establish, and subsequent migration to full commercial deployment is also not guaranteed.

Enterprise and industrial users and those working within dedicated spaces may favour private 5G networks

Enterprise and industrial users (e.g. transport, manufacturing) and/or those working within dedicated spaces (venues and stadiums, manufacturing floors) might be key areas where 5G private networks may be favoured over public networks. Mobile operators around the world are still adjusting to offering differentiated enterprise and vertically-focused solutions using tailored 5G connectivity, and will take time to implement the latest network functionalities offered by the most recent 3GPP (i.e. 5G standard) releases in their public networks. Additionally, standardised or fully commercial vendor offerings are still being established based on the latest 5G standards. As a result, short-term demand from 'early adopters' in industrial or enterprise segments may be addressed by private networks. Key features of private networks might include: vertically-focused solutions; on-site data security and data processing; network control; flexibility to tailor uplink and downlink capacity distinct for dedicated spaces.

5G applications that might be delivered using dedicated private networks include use cases where specific connectivity guarantees (e.g. in terms of capacity, reliability or latency) might be needed: examples of use cases included industrial use of AR/VR, industrial use of UHD video, autonomous vehicles or machines (in a factory, campus or enterprise site); automated guided vehicles, or AGVs (in a factory or port environment); mission-critical or remote object and machine manipulation, robotics, sensor networks (in a dedicated/defined space).

Some 5G applications are more suited to public networks

5G applications that would be more suited to public networks include use cases requiring wide-area coverage or wide-area mobility, e.g. high-speed broadband (FWA home and office, consumer mobile connectivity on handsets); connected vehicles (ambulances, buses, passenger vehicles on roads); sensor networks (for smart cities, logistics and distribution, public services consumer groups); smart tracking.

3.3 Consumer group benefits and beneficiaries

The users of 5G within each of the consumer groups identified in the previous section are a mixture of individual consumers, households, businesses and the public sector. Whether and how different users decide to invest in a 5G product or solution will vary between business-to-consumer (B2C) and business-to-business (B2B) 5G services. Given that 5G modems and subscriber identity modules (SIMs) can be embedded into different types of products (vehicles, machines and other types of equipment in the IoT), there is also a business-to-business-to-consumer (B2B2C) category of 5G services.

These different modes of consumption of 5G services can be considered as follows:

- B2C: This refers to 5G connectivity consumed directly as a service, e.g. individual consumption for 5G-based fixed wireless access (FWA) and mobile broadband. Broadly speaking, B2C services are what previous generations of mobile technology have focussed on. In the 4G era in particular, the mobile industry has been successful in expanding the market for B2C services via smartphones, including video streaming, e-sports and a wide range of mobile-focussed applications (e.g. taxi booking applications such as Uber, social media applications). The range of potential B2C 5G services is vast, and 5G is likely to bring more immersive consumer experiences such as immersive retail, media and entertainment, as identified by the use cases and consumer groups discussed in the previous section of this report.
- B2B: This refers to 5G connectivity used within business and/or industrial processes. 5G for businesses is poised to be where the most transformative applications of 5G emerge, with consequential benefit through cost savings and productivity enablement – for example a 5G-connected machine or sensors in a production line that could either enable products to be produced more quickly, or equipment downtime to be avoided through predictive maintenance, for example.
- B2B2C: This refers to 5G-enabled solutions and connectivity embedded into end-consumer products – these embedded solutions might include 5G-connected vehicles, 5G-connected CCTV, 5G-enabled health monitoring systems and so forth. For B2B2C 5G services, the user is likely to purchase 5G connectivity as part of a solution being purchased from another business. This B2B2C 5G service category might include 5G buyers in the public sector, as well as firms and individuals.

A summary of the predominant mode of consumption for 5G in different consumer groups and relevant sections is included in Table 3-5 below.

Table 3-5: Predominant mode of consumption for 5G in different consumer groups

Consumer group	Sector	B2B	B2C	B2B2C
Media and Entertainment	Gaming			✓
	Media	✓	✓	
	Venues and events	✓	✓	
Public services	Health and social care	✓		✓
	Education			✓
	Public safety and security	✓		✓
Energy and utilities	Utilities	✓		✓
	Oil and gas	✓		✓
	Mining	✓		
	Renewables	✓		✓
Rural industries	Agriculture	✓		✓
	Forestry	✓		✓
	Fishing	✓		✓
	Tourism	✓	✓	✓
Smart urban	Smart cities	✓	✓	
	Construction	✓		✓
	Professional services	✓		
	Tourism	✓	✓	
Transport	Public transport	✓	✓	
	Automotive	✓		✓
	Airports	✓	✓	
	Water transport	✓	✓	
Manufacturing, logistics and distribution	Freight	✓		✓
	Ports	✓		✓
	Smart factories	✓		✓
High-speed broadband into homes and offices	Home broadband		✓	
	Office broadband	✓		
Retail and hospitality	e-commerce	✓	✓	
	Hospitality	✓	✓	

Source: Analysys Mason

The main factors considered when deciding to invest in 5G can vary between the different modes of consumption and the business case for 5G is intrinsically linked to an individual use case. Analysys Mason's Research Division publishes connected consumer surveys for different world regions, and for different types of telecommunications service – mobile, TV, video, digital services, over the top (OTT) services etc. In a recent mobile survey, a key finding was that respondents were primarily interested in the ability of 5G to improve download speeds, video resolution and gaming performance. For example, new 5G services that individual consumers expressed interest in paying more for included AR/VR services such as virtual chatrooms, immersive gaming and in-car entertainment. (Analysys Mason, Connected Consumer 2020: 5G, data consumption and monetisation). For B2B and B2B2C 5G services, interest in 5G is potentially also driven by the use cases offered, albeit that these use case might be packaged differently to those offered to individual consumers. Hence, it is likely to be the more innovative services that showcase 5G in the B2B and B2B2C sectors, such as AR/VR.

Since these services will help to stimulate demand for high-performance connectivity more generally, the speed and latency advantages of 5G will have a key role to play.

Based on the literature we have reviewed for this study and the evidence presented to us during the study, we have identified the following criteria that different types of users and modes of consumption (B2C and B2B) might consider when investing in 5G. The criteria for B2B2C investment in 5G depends on whether utility of 5G is primarily accrued to individuals or businesses and as such sits across the criterion outlined below. When choosing a 5G solution, individuals and businesses will inevitably consider how 5G compares with existing and/or alternative solutions available to address the envisaged uses (e.g. 4G, fibre, Wi-Fi, etc.). These considerations are reflected within the various criteria shown below such as price, coverage, etc.

Table 3-6: Criteria for investing in 5G – individual consumers and households (B2C)

Criteria	Description
Price	• The cost of devices plus the monthly charge, but also including factors such as price compared to existing solutions (e.g. 4G) data allowances, the functionality of new devices, choice of mobile provider, customer services offered etc.
Coverage	• The total coverage or coverage in specific locations relevant to an individual consumer (where I live, where I work, indoors etc.) • How 5G compares to coverage from existing solutions (4G, Wi-Fi) in the specific locations
Data speeds	• The improvement in user experience and engagement that the 5G service / device offers (compared to an existing solution, if relevant), and/or better quality for services used currently via existing solutions (e.g. quality of entertainment)
New services	• This refers to new services that 5G might enable that are not available via existing solutions (AR/VR, immersive content, e-sports, etc.) • B2C consumers might also be attracted to 5G as an alternative way of receiving a broadband connection, which might be considered a new service for individual or households (e.g. 5G FWA instead of fibre or fixed broadband) • Supplier influence might also be a factor in new services (e.g. MNOs or device manufacturers promoting new services using a 5G smartphone to incentivise 4G users to upgrade handsets to a 5G-enabled device)
Perception of the technology	• This includes individuals being concerned about health risks from 5G as well as awareness of the technology and the benefits it brings

Source: Analysys Mason.

Table 3-7: Criteria for investing in 5G – businesses and the public sector (B2B)

Criteria	Description
Price	• Total cost of ownership, total deployment cost, opex and other equipment-related spend needed to enable the 5G use cases, over the lifetime of the equipment • Cost-benefit analysis (e.g. comparison of the cost of a 5G solution compared to existing ones, compared to the additional functionality/benefits provided) • Extent to which 5G supports specified improvements within the business (cost savings, productivity, reduced machinery downtime, additional data insights or visualisations etc.) • The contribution to the investment made by suppliers and the incentives offered (e.g. scope of contract offered, payment, models, service level agreements)
Supplier push	• This refers to network provider choice/influence of mobile providers – some B2B users who already use non-5G services from an MNO might be encouraged by the MNO to migrate to a 5G solution
Coverage	• The total coverage or coverage in specific locations relevant to the business (which might include coverage for an individual campus or factory, or for multiple locations across the UK, or across international locations)
Data speeds	• The improvement in user experience that the 5G service / device offers, which include better quality for services used as well as factors such as reliability, network availability
New services	• Demonstration of the ability of 5G to deliver specific use cases that the business needs, including adding mobility to use cases that the business already makes use of via a fixed network; for example, for health workers who have access to real-time video applications or other visual tools (e.g. precision geo-mapping) whilst indoors or in the office, 5G might enable access to the same tools whilst outdoors or on the move, in a way that could not have been delivered using 4G due to constraints of bandwidth/latency of connection
Risks and feasibility	• Associated risks of the 5G investment (which might be tested via a proof of concept ahead of full investment) • Practical implementation issues • Availability, catalogue and lead time on hardware/software to deploy 5G
Return on investment	• How costs can be recovered over the lifetime of the investment
Security	• Assurance that the network security features offered by the proposed 5G installation meets business requirements

Source: Analysys Mason.

3.4 The benefits of 5G

Several challenges mean the existing evidence on benefits is limited and uncertain

Compared to previous mobile broadband standards, 5G is designed to enable a wider range of use cases and applications; and thus, a potentially greater range of benefits.

While the identification and conceptualisation of these benefits is relatively well evidenced (but evolving, as new use cases emerge), the quantification of these benefits is limited and subject to uncertainty.

One key reason for this is that 5G is a relatively new technology that, as of early 2021, is only just beginning to be rolled out in the UK and around the world, and will evolve as further investment is made into services and solutions. This means there are very few empirical data on the roll out, adoption and application of 5G. In the absence of such data, it is difficult to estimate the scale and nature of benefits associated with 5G.

Existing estimates either rely on subjective assessments of the impact of 5G or assume 5G is comparable to previous technologies

Existing studies have attempted to estimate the overall impact or benefit of 5G. However, faced with the same data limitations, these studies all provide *ex ante* estimates which either rely on assumptions about the nature and scale of the adoption of 5G and the benefits it brings; or draw on the empirical evidence on the evolution and impact of previous technologies, such as 4G, to approximate or make assumptions about how 5G will be adopted and the benefits it will bring.

Both approaches have limitations. Studies based on the impacts of previous technologies can use robust estimates of these impacts but are restricted by the assumption that 5G is comparable to previous technologies. Studies which forecast the impact of 5G based purely on expert assessment can assume that the impact of 5G will be more transformative, but such forecasts are highly subjective. The trade-off between the extent to which these studies are grounded in empirical data and the extent to which they consider the specifics of 5G reflects the limited evidence base.

Non-linear benefits are not well evidenced

Another limitation of the evidence base is that many of the benefits apply a standardised (impact per user) approach. In reality, it is likely that the benefits of 5G may not grow linearly with the number of users. A general weakness of the evidence base is that it does not provide very much insight into non-linear benefits (e.g. critical mass effects, positive/negative feedback effects).

Few, if any, studies provide a comprehensive assessment across the different types of benefits

Finally, there are few studies which quantitatively bring together benefits in social, economic and environmental spheres. For example, separate studies may address productivity gains in manufacturing and social gains in wellbeing of healthcare patients, but few papers found in the evidence review brought together these diverse benefits in a comparable and commensurable way.

Issues specific to individual users groups are also identified for a number of cases. For example, where estimates based on stakeholder participation may lack precision or be subject to optimism bias; where estimates based on case studies or small pilot studies may not be a reliable indicator of the potential benefits industry-wide. In other studies, the additionality of 5G for the benefits of applications supported by multiple connectivity technologies is often not identified and thus uncertain; or based on expert but subjective judgement. There is also a tendency for existing studies to focus on the economic benefits and overlook non-market social benefits or environmental benefits.

Nonetheless, below we summarise the broad types of benefits identified in the literature and how these might be felt across the different consumer groups.

Broad types of benefits

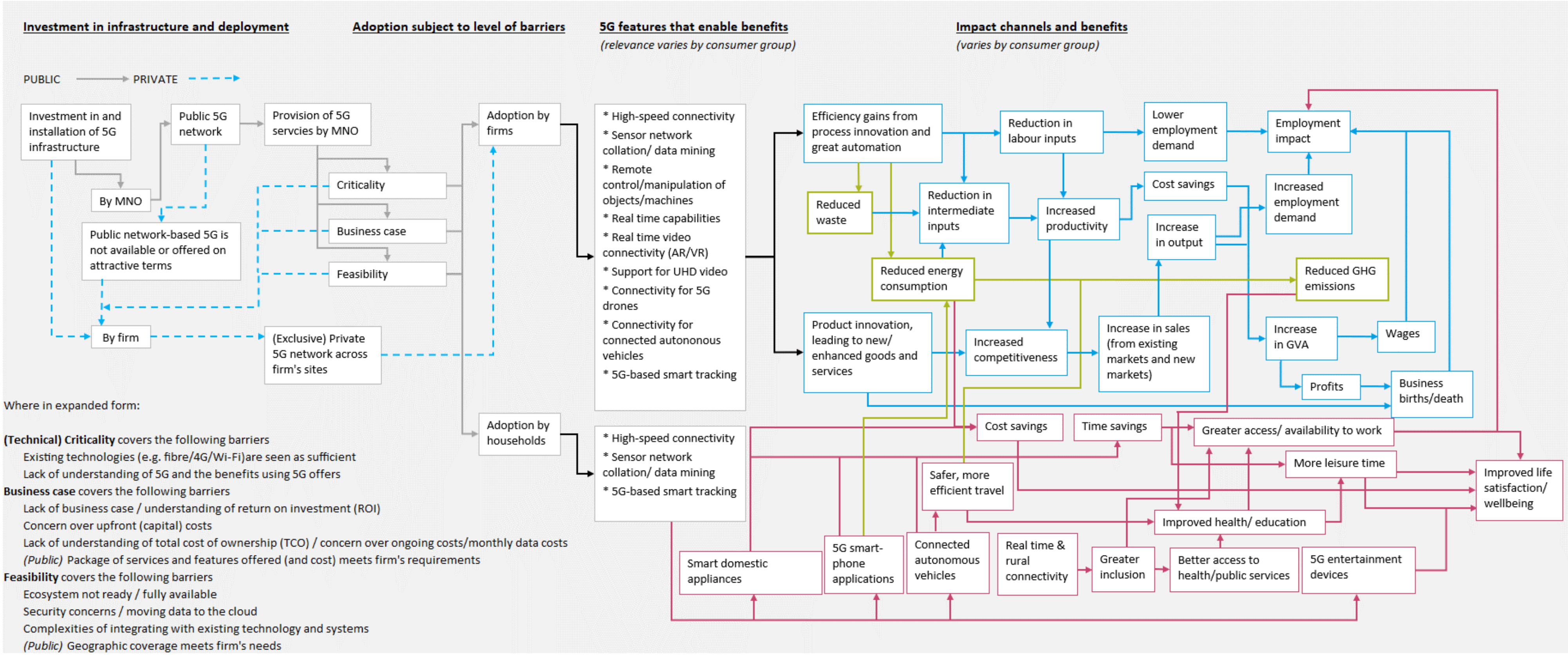
Types of benefits identified in the literature can be summarised as follows and are captured in the logic map in Figure 3-1:

- **Economic benefits** – The most often cited economic benefits of 5G use are increased productivity to firms and additional GDP growth (in many cases linked to increased productivity). Economic benefits are also often expressed in terms of cost reduction – for instance, when assessing the economic benefits of 5G use on costs to the healthcare sector. These economic benefits of 5G adoption are realised through a wide range of mechanisms, including: reductions in factory downtime; lower defect rates in manufacturing; energy efficiency gains; and reduced waste. Other economic benefits identified in the literature are linked to the enabling effects of 5G, including the creation of new business models and businesses, increased labour force participation and the launch of new products or services.
- **Social benefits** – Social benefits associated with 5G use cases include increased life expectancy, improved public safety, better health, reduced loneliness, and overall improvements in self-assessed quality of life and life satisfaction metrics. Some social benefits arise from time savings linked to increased productivity in housekeeping and reduced travel times. Many studies note indirect social benefits as a result of improved economic and environmental conditions; however, these tend to be described qualitatively.
- **Environmental benefits** – Many of the environmental benefits of 5G are linked to efficiency gains related to transport activities and the consumption of energy and natural resources. These benefits include reductions in traffic congestion and GHG emissions, reductions in the use of energy, and lower consumption of natural resources, such as water. Another key source of environmental benefits is linked to reduced demand for travel due to improved connectivity and an increase in remote working. Some environmental benefits are specific to particular consumer groups.

Benefits to Consumer Groups

- **Media and entertainment** – 5G will enable multiple new products and experiences that could not be supported by older technologies, such as VR experiences, augmented reality, cloud gaming and new media. The economic benefits of these new products can be quantified based on the additional revenues that these products are expected to generate, which translates into additional output and GVA. Some studies also quantify the environmental benefits of reduced travel due to remote participation in events.

Figure 3-1 Logic map of 5G adoption and benefits



Where in expanded form:

(Technical) Criticality covers the following barriers
- Existing technologies (e.g. fibre/4G/Wi-Fi)are seen as sufficient
- Lack of understanding of 5G and the benefits using 5G offers

Business case covers the following barriers
- Lack of business case / understanding of return on investment (ROI)
- Concern over upfront (capital) costs
- Lack of understanding of total cost of ownership (TCO) / concern over ongoing costs/monthly data costs
- *(Public)* Package of services and features offered (and cost) meets firm's requirements

Feasibility covers the following barriers
- Ecosystem not ready / fully available
- Security concerns / moving data to the cloud
- Complexities of integrating with existing technology and systems
- *(Public)* Geographic coverage meets firm's needs
- Cultural resistance to change

- **Public services** – The benefits to healthcare stem from cost savings enabled by 5G technologies as a result of cheaper remote consultations and remote care, more efficient chronic healthcare provision and real-time monitoring of patients in clinical trials. The use of wearable health devices results in better health outcomes and lower healthcare costs. 5G-enabled technologies enable better provision of social care, which results in additional social benefits, such as reduced loneliness and improved quality of life. The benefits to the education sector include improved efficiency and better learning outcomes due to better collaborative tools and AR applications. 5G will also benefit public safety due to improved monitoring and security devices, resulting in saved lives, and reduced damage from burglary.
- **Energy and utilities** – 5G is expected to bring substantial energy efficiency improvements due to its application to smart grids and smart meters within utility companies themselves (such as remote expert support for employees working in hazardous environments, 3G imaging of underground assets, real-time video links, etc.). These are often quantified in the literature as economic benefits (efficiency leading to energy cost savings) as well as environmental benefits (reduced GHG emissions). Similar technologies are also expected to reduce water use.
- **Rural industries** – The benefits are particularly important to agriculture, where 5G will enable better monitoring of crops and livestock. The benefits include higher crop yields, lower healthcare costs for livestock and time savings. More efficient use of pesticides is also expected to generate some environmental benefits. Overall, rural economies are also expected to benefit from improved connectivity, which previous technologies could not provide cost-effectively. These benefits include reduced cost of high-speed connectivity and bringing households online, which is expected to generate additional economic benefits through increased use of e-commerce. There may also be social benefits associated with decreased isolation and loneliness. However, the main existing evidence that addresses social impacts of 5G on loneliness (notably the Liverpool 5G Testbed) analyses 5G in an urban setting.
- **Smart urban** – Deployment of 5G-enhanced traffic management systems (as one example of many smart urban use cases) is expected to reduce congestion, generating economic and environmental benefits, such as shorter travel times and lower GHG emissions. The use of drones for inspection of urban areas will result in efficiency savings, reducing labour time.
- **Transport** – In road transport, 5G will enable technologies such as connected and autonomous vehicles. These technologies will result in economic benefits due to more efficient utilisation of vehicles and reduced congestion. These directly translate into further environmental effects. Improvements in vehicle connectivity will enable better telematics used for remote diagnostics and additional experiences for passengers. These are valued in terms of monetary benefits per vehicle utilising these technologies. Water transport benefits will be driven by efficiency gains at ports, stemming from automation of operations and lower congestion.
- **Manufacturing, logistics and distribution** – 5G technologies will boost productivity at smart factories, with technologies such as AR remote support, digital tracking and advanced predictive maintenance expected to

reduce repair costs and downtime. AI cameras, environment monitoring within the factory and AR-powered warehouse operations will result in improved quality management. This will reduce out of spec production, resulting in greater output, and lower GHG emissions and waste. Nascent delivery drone logistics are expected to take over last mile delivery, resulting in faster delivery and cost savings.

- **Retail and hospitality** – 5G use cases in the retail sector will enable warehouse and supply optimisation, resulting in increased productivity. New AR shopping experiences will enable additional revenue, increasing the retail sector's output. Also, AR applications will enable new experiences to visitors, which will contribute to the tourism sector's output.
- **Broadband/super-fast connectivity** – super-fast wireless connectivity will enable widespread use of cloud computing. Cloud computing gives access to superior resources on demand, resulting in increased productivity, and in turn, in GDP growth. Cloud computing is also more energy efficient, leading to additional environmental benefits in the form of lower GHG emissions. 5G is also expected to provide super-fast connectivity to areas not benefitting from comparable wired connections. Improved connectivity will enable additional economic activity in these areas, resulting in GDP growth and an increased labour participation rate.

3.5 Estimates of the magnitude of the benefits

In many studies the benefits are quantified at an aggregate economy-wide level

A substantial strand of literature takes a high-level approach to estimating the economic benefits of 5G. Due to the variety of use cases across multiple consumer groups, 5G is treated as a general-purpose technology (GPT) and the benefits are quantified at an aggregate economy-wide level. Studies taking this approach tend to draw on historical evidence by assuming that the impacts of 5G will be similar to the impacts of previous revolutionising technologies on productivity growth or GDP growth

Other studies (Accenture 2018) (Oxera 2019) look at the past relationship between connectivity speed and macroeconomic performance indicators, such as GDP growth and business creation rate. By assuming that these relationships will hold in the future, these studies estimate the contributions of 5G-enabled super-fast connectivity to future GDP growth or growth in the number of business establishments and employment.

Top-down estimates of economy-wide benefits

The estimates of the economy-wide benefits of 5G by the Australian Government (2018) assume that the productivity growth impacts will be similar to those attributed to other general-purpose technologies in the past, such as steam technology, mobile phones, or ICT. The study utilises various assumptions based on these findings and the projections of 5G adoption, which results in 18 scenario variants. Depending on the scenario, it is estimated that 5G adoption in Australia will increase the productivity growth rates by between 0.05% and 0.23%. These increases could occur over 10 years in some scenarios, while other scenarios assume that the effects will continue for 30 years (assuming that 5G is a more transformative technology).

A similar approach has been taken in GSMA (2018) which assumes that the maximum annual GDP growth rate enabled by 5G could reach 0.28%

worldwide. This value is informed by studies evaluating the past contribution of broadband and mobile telecommunications to global economic growth. To obtain GDP contributions by industry, 5G-enabled growth was distributed across industries based on an assessment on how 5G use cases are relevant to each industry.

Barclays (2019) estimates that the 5G roll-out in the UK will result in additional output of between £8.3bn to £15.7bn in 2025, depending on the roll-out scenario. Correspondingly, the impacts by 2030 could range between £51.9bn and £89.6bn of additional output. These findings rely on modelling using the evidence accumulated through desk research and business survey results.

Accenture (2018) estimates the benefits of 5G based on the impact of previous generations of wireless connectivity in Canada. It finds that a 10% increase in mobile network users from one quarter to the next generates, on average, a 0.6% increase in GDP. The study extrapolates this result to obtain the potential contribution of 5G to Canada's GDP in the future.

Other studies rely on the estimated impacts of wired broadband. Oxera (2019) estimates the combined impacts of super-fast fibre and 5G deployment. It predicts an impact on productivity at between 0.3% and 3.8% as a result of super-fast connectivity, basing this on findings on the impact of wired broadband from IPSOS Mori (2018) and Ericsson, Arthur D. Little and Chalmers University of Technology (2013). Additional impacts estimated by Oxera (2019) include increase in the number of businesses operating in the area benefitting from superfast connectivity, at between 0.4% and 3.2%, also based on findings from other studies (Ericsson, Arthur D. Little and Chalmers University of Technology 2013) (Hasbi 2017).

Some relevant findings are available on the economy-wide applications of technologies related to 5G. CEBR (2016) estimates the value of big data and IoT to the UK economy. The expected benefits of IoT in the UK over 2015-20 are valued at 0.7% of annual GDP. In other words, a 1% increase in IoT adoption results approximately in a 0.02% increase in GDP. A study by AT Kearney (2016) estimates that IoT could increase GDP growth by 7 percentage points through productivity growth and value redistributed to end consumers in the EU. Approximately 30% of that impact is attributed to energy savings and increased product durability, 20% is attributed to freed up time, 42% is due to productivity gains and 8% is the value of the IoT devices market revenues.

Similarly, Deloitte (2019) estimates the potential impacts of 5G in Scotland as a result of economy-wide cloud computing applications. The study borrows from a previous study for the European Commission, which estimated that in the EU for every 1% increase in cloud computing adoption, there is an approximate 0.04% increase in GDP. The same Deloitte (2019) study relies on CEBR (2016) study on UK SMEs, finding that cloud computing adoption results in 0.02% increase in productivity per 1% increase in cloud computing adoption. Additionally, the evidence from CEBR (2016) suggests that data analytics and IoT will lead to creation of new businesses (3% and 5% respectively).

However, given that IoT and big data applications can be supported by communications technologies other that 5G, it is unclear how much of these benefits should be attributed to 5G-enabled capabilities.

5G as a 'general purpose technology'

An important and recurring finding of evidence analysed in this study was that the role of 5G in future economic activity is highly uncertain. Studies (or scenarios within studies) therefore need to take a stance on whether 5G will have transformative and pervasive impacts on future economic activities or will instead result in modest improvement to performance in limited sectors of the economy. The former stance sometimes categorises 5G as a 'general purpose technology' (GPT) – a technology which is characterised by "pervasiveness, inherent potential for technical improvements and innovational complementarities" (Bresnahan and and Trajtenberg 1995). Typical examples of GPTs include steam power, electricity and ICT.

As a part of this study, estimates of the economic impacts of previous technologies were collated and compared, including both GPTs (e.g. electricity, steam etc) and technologies more comparable to 5G (4G/3G). This was then critically evaluated to inform scenarios in the economic model (see Section 7.1). The full list of economic impact estimates – expressed as a percentage point uplift in growth and standardised where possible – is shown in Figure 3-2:

Figure 3-2: Economic growth uplift across the full list of estimates from collated studies (GPT & 5G-related technologies)

Sources: Cambridge Econometrics analysis; (Qiang, Rossotto and Kimura 2009); (Edquist, Goodridge and Haskel 2021); (AT Kearney 2016)…

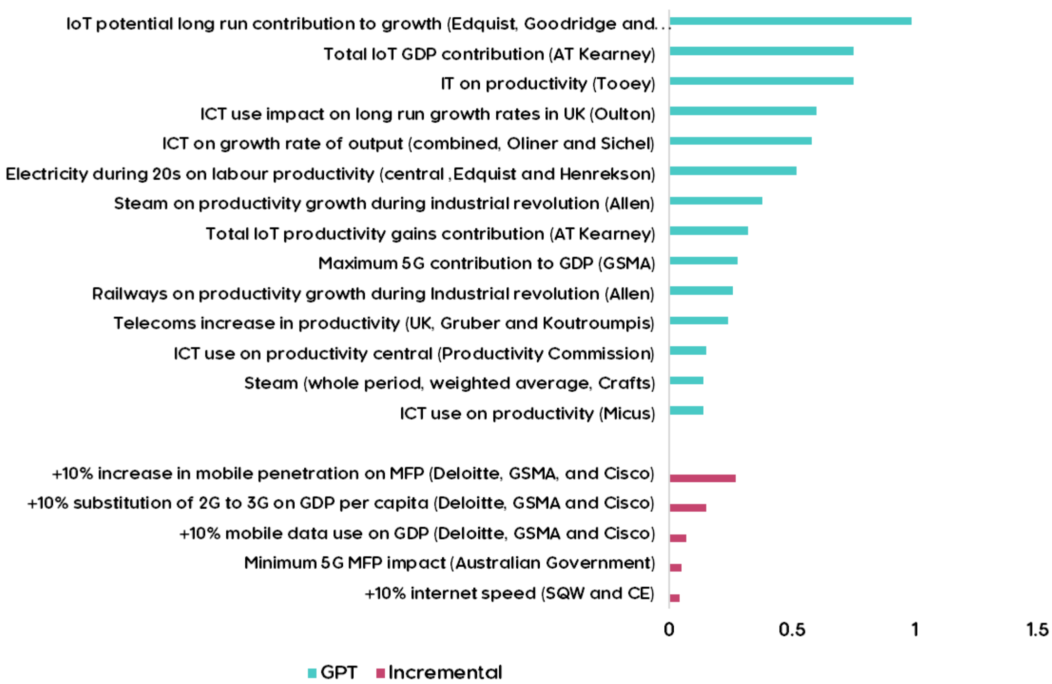
These results were further critically assessed by:

- condensing multiple estimates from the same study but across different years;
- condensing multiple estimates where a high/low estimate is provided (unless the difference between high & low estimates explicitly corresponds to GPT vs non-GPT scenarios); and
- categorising studies into groups (GPT or 'incremental' improvement / non-GPT technologies).

Some papers were also removed from the shortlist due to extreme results and/or the studies' ability to attribute causality (e.g. Qiang, Rossotto and Kimura (2009)). The result of this critical analysis is shown in Figure 3-3.

The study finds that general purpose technologies tend to report a higher impact than 'incremental' technologies. The median impact estimate of the former was 0.35pp, while the median impact of the latter was 0.7pp.

Figure 3-3: Economic growth uplift across a shortlist list of estimates from collated studies (GPT & 5G-related technologies)



This exercise is however indicative and is highly sensitive to the way in which the shortlist of papers are selected and organised. Moreover, comparing across papers in this way presents additional challenges of consistency because the various studies adopt different assumptions, consider different eras and report impacts on different economic variables (e.g. GVA vs multi-factor productivity).

Economic benefits across consumer groups

The evidence analysed in this study suggests that 5G benefits to the manufacturing sector – stemming from higher productivity and lower waste – are likely to be large in magnitude. Benefits estimated vary from a 4%

increase in GDP (by 2030) (STL Partners and Huawei 2019), to a 5.4% increase in annual revenues (by 2035) (IHS Markit 2019), and a £2.6bn increase in revenues of the manufacturing sector in the UK (by 2026) (W5G 2020).

Productivity benefits are expected to generate large cost savings to the UK logistics sector (£2.8bn by 2030) and correspond to increases in the UK sector's GDP (£1.2bn by 2030). Evidence from case studies suggests that this will be boosted further by automation in ports.

Media and entertainment markets are expected to benefit from 5G (predominantly via VR/AR applications). Estimates in the literature suggest that this could increase the size of the media and entertainment sector by 4% by 2030.

Cost savings are expected for public services (principally health and social care), as a result of healthier lifestyles, remote provisioning and remote monitoring (e.g. medication monitoring). One study estimates that this will boost EU28 healthcare sector's annual GDP by €235bn by 2025. Evidence from the Liverpool 5G testbed indicates that cost savings will be in the region of £2,500 per user per year. It is anticipated that the energy and utilities sector too will experience a number of operational benefits, with an estimated annual impact on the sector's GDP contribution at 4.7% by 2030 according to one study.

5G is expected to aid the Rural economy by boosting crop yields of arable land and enabling better monitoring of livestock health in agriculture; and by assisting with tourism (evidenced by an example application in the Pennines) in rural areas.

Environmental benefits

Evidence of environmental benefits are also present in the literature, predominantly relating to greenhouse gas (GHG) emissions savings as a result of 5G-enabled applications in energy and utilities (up to 6.4MTCO_2 per year) (O2 2018), reduced traffic and congestion (up to 370,000 tonnes of CO_2 emissions per year in Scotland alone) (Deloitte 2019), GHG savings in logistics (in a case study of a pilot deployment in a port, the result was a 8.2% reduction in the port's emissions) (Ericsson 2020), reduced waste in manufacturing (Ericsson 2019) and general 5G efficiency gains compared to previous generations.

Social benefits

Wellbeing and life satisfaction

For certain use-cases – most notably in Health and Social Care applications – there is evidence of improvements to the users' perceived sense of wellbeing. Liverpool 5G Health and Social Care Testbed (2019) identified the following social impacts:

- **Life satisfaction impacts** – VR simulations (quizzing and gaming apps) were found to increase reported life satisfaction by 1.4 points (out of 10). Safehouse technologies (used to monitor the environments of vulnerable individuals) were found to increase reported life satisfaction by 0.7 points (out of 10).
- **Loneliness / isolation impacts** – VR simulations (quizzing and gaming apps) were found to lead to: a 28% decrease in those who said that they

often felt that they lack companionship; a 20% decrease in those who said that they often felt left out; and a 13% increase in those who said that they hardly ever felt isolated from others. Push-to-talk services (5G-supported hardware to enable individuals from vulnerable groups to connect and talk) were found to lead to: a 25% increase in those who said that they hardly ever felt that they lack companionship: a 75% increase in those that said they hardly ever felt left out; and a 50% increase in those who said they hardly ever felt isolated from others.

Confidence and independence – Medication support services were found to lead to: a 73% increase in those confident and happy to take medication; a 53% increase in those who felt safe; and a 40% increase in service users who felt more independent.

4 5G marketplace and readiness in the UK

While the focus of this study is on understanding the drivers and benefits of 5G adoption, and the impact of barriers to adoption on the realisation of benefits, it is still helpful to step back and take stock of the state of play in the UK 5G market. This helps to understand the current state of development of the UK 5G market and how that is likely to change in future. This chapter provides an overview of the current UK 5G marketplace with regard to recent developments in the evolution of the 5G market, spectrum deployment, network architecture, and standards; including the readiness of the UK for 5G deployment and adoption.

4.1 Recent developments

MNOs first deployed 5G services in 2019

Mobile network operators (MNOs) in the UK commenced their launch of 5G services in selected locations in 2019. These initial 5G services have predominantly targeted individual consumers of mobile broadband (MBB) services. For these users, 5G radio means greater capacity for the services they already use on smartphones and other mobile devices. 5G MBB therefore offers faster mobile data connections for video downloads, live streaming and gaming, offering a step change in quality of experience for these services compared to slower, 4G-based MBB.

5G networks are being expanded to address a diverse range of users and uses

The UK's 5G networks are being progressively expanded by MNOs to address a larger coverage footprint and in so doing, to address a wider market. This wider market is expected to include a diverse range of 5G users and uses, including business and enterprise customers, industrial companies, creative industries, media, aviation and transport sector, utilities and many more.

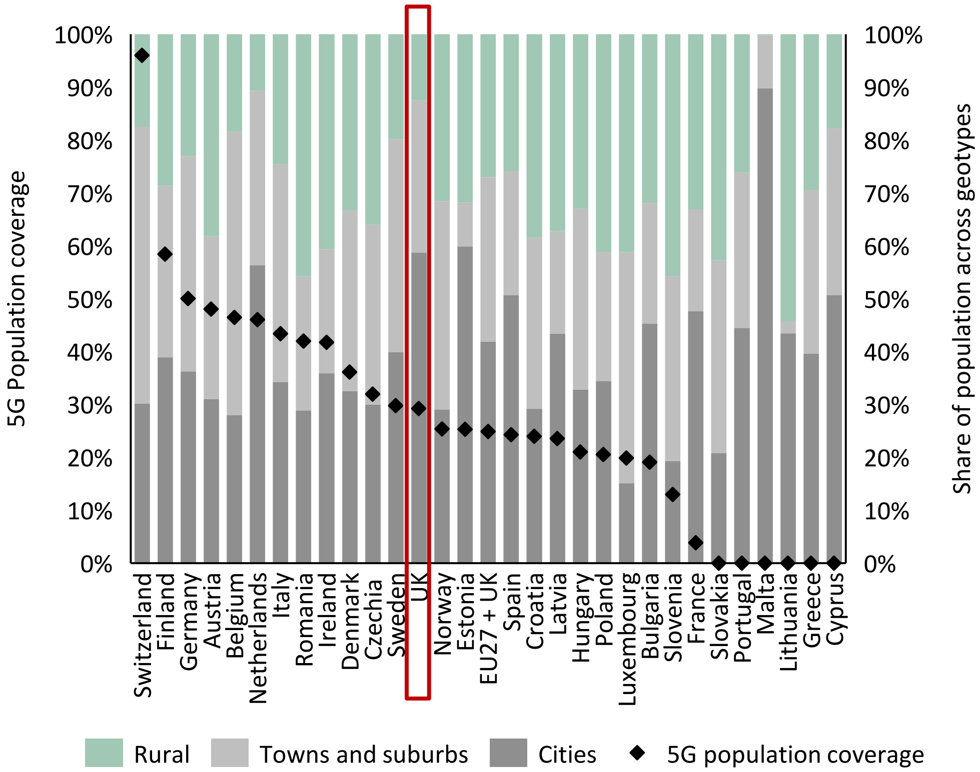
Roll out is largely on the basis of population density

From published data on UK 5G network coverage it appears operators are following a largely population-led MBB capacity-driven approach to initial 5G roll-out, targeting locations with highest density of individual MBB consumers, equivalent to locations with the highest population density.

5G coverage in the UK is above the European average

Using data available from the GSMA (GSMA 2021), we can estimate that the 5G coverage in the UK was c.30% of the population as of Q4 2020, placing it slightly above average for European countries where 5G services have been launched (see Figure 4-1). Most of the coverage upon which the estimates above are based are using 3.5GHz spectrum. However, in markets in Europe where 3.5GHz spectrum is not yet available, there is 5G coverage being provided using existing mobile bands, such as 2.1GHz, using technology solutions to enable 4G/5G traffic sharing within the operators licensed spectrum. Since this data was published, we note that Vodafone has implemented this sharing solution in its 2.1GHz spectrum, to expand its '5G' coverage in the UK.

Figure 4-1: 5G coverage in the UK and European countries, Q4 2020



Notes: 5G population coverage in European countries (black diamond), overlaid onto the share of the population across three geotypes: cities, towns and suburbs, and rural. The chart does not indicate the split of 5G coverage across these geotypes.

Source: (GSMAi 2021), (Eurostat 2021), Analysys Mason.

To date, deployment of 5G by MNOs has been 'non-standalone'

Like other 5G early-adopter countries, the UK's 5G infrastructure deployed by MNOs to date has been based on adding 5G radio to existing 4G infrastructure (a deployment referred to as 'non-standalone'). This approach was adopted in recognition of factors including device availability, network equipment limitations, cost, and the need for rapid early deployment.

The government's test beds and trials programme is being used to accelerate the roll out and use of 5G

In its 5G strategy published in 2017[6], the UK Government set out a clear ambition for the UK to be a global leader in 5G. To this end, the Government is investing in a nationally coordinated programme of 5G testing, which is the 5G Testbeds and Trials programme being coordinated by DCMS. The Testbeds and Trials programme has at its core key goals to accelerate the availability of 5G infrastructure, and the use of 5G, thereby creating opportunities for UK businesses and drive productivity and efficiency benefits for the UK economy through 5G deployment and use.

The Testbeds and Trials programme is testing 5G deployment via multiple local deployments, typically based on stand-alone 5G radio and/or core network infrastructure separate from wider commercial 4G/5G implementations.

[6] A 5G strategy for the UK, 2017 and Next Generation Mobile Technologies: An update to the 5G strategy for the UK, December 2017

Several MNOs have also commenced 5G pilot projects (including projects funded via DCMS's Testbeds and Trials and the associated urban connected communities/rural communities projects, as well as their own test facilities).

These various 5G pilots and test networks are aimed at widening the 5G market to diversify use cases and to deliver connectivity to different consumer groups, including industrial sites, enterprise services and automotive. Findings from these testbeds and trials are discussed in standalone Appendix A.

4.2 Spectrum used in UK MNO 5G deployments

Spectrum for 5G rollout has been harmonised at a European level

The characteristics of 5G new radio are such that full capabilities of 5G technology are delivered when the technology is deployed in wider contiguous blocks (because there is a trade-off between available bandwidth, and reliability/latency performance of 5G radio, since different transmission paths can be shaped for different services[7]). In European markets, spectrum for 5G is being made available in the three 5G pioneer spectrum bands that have been harmonised for 5G use across Europe; the European harmonised bands for 5G are referred to as the 700MHz band (703-788MHz), the 3.5GHz band (3.4-3.8GHz) and the 26GHz band (24.25-27.5GHz).

Initial 5G network launch in the UK took place using spectrum in the 3.5GHz band (from 3.4-3.6GHz), which was auctioned to MNOs in 2018. Additional spectrum suitable for 5G use was auctioned by Ofcom in 2021. Final results of Ofcom's spectrum auction for the upper part of the 3.5GHz band (3.6-3.8GHz), together with the 700MHz band were published in April 2021[8].

Assignments from the auction have subsequently been updated through a trade of spectrum between Vodafone and Telefonica, with details confirmed by Ofcom in July 2021[9]. The trade of spectrum will require the respective operators to carry out site upgrades and to share use of the two blocks until end of 2025. Thereafter, the assignments of spectrum between UK MNOs in the band between 3.4-3.8GHz (correct at the time of publishing this report) is as shown in Figure 4-2 below.

The spectrum as shown below is available to individual MNOs on a nationwide basis. All four MNOs have launched 5G services in their nationwide networks in selected (mainly urban) UK locations using this spectrum, together with other spectrum bands available to MNOs.

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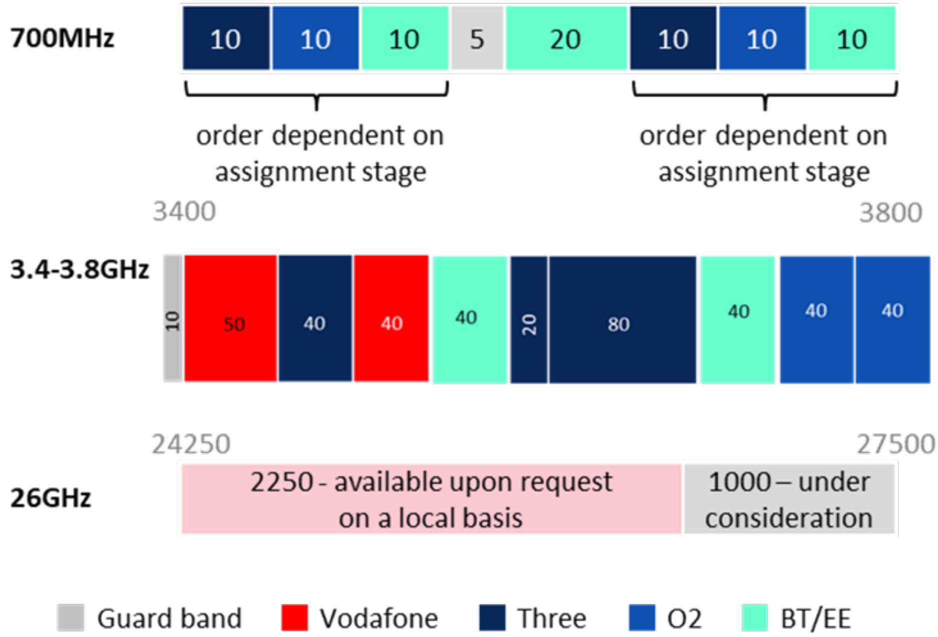
[7] Ofcom considered the bandwidth needed for 5G services as part of its consultation on award of the 700MHz and 3.6GHz spectrum, here https://www.ofcom.org.uk/__data/assets/pdf_file/0023/195521/consultation-sut-modelling-700mhz-3.6-3.8ghz-spectrum.pdf. Ofcom concluded that it is technically feasible for mobile network operators to support 'a wide range of 5G services' with a spectrum bandwidth of less than 80MHz, but with user experience (data rates, reliability and latency) depending on the loading of the network.

[8] Ofcom spectrum auction: final results announced - Ofcom

[9] Mobile and wireless broadband - Ofcom

In March 2021, Ofcom concluded the first stage of its 3.6-3.8GHz and 700MHz spectrum auction, confirming the amounts of spectrum awarded to each MNO.

Figure 4-2: UK 3.4-3.6GHz spectrum band plan, including March 2021 award (MHz)

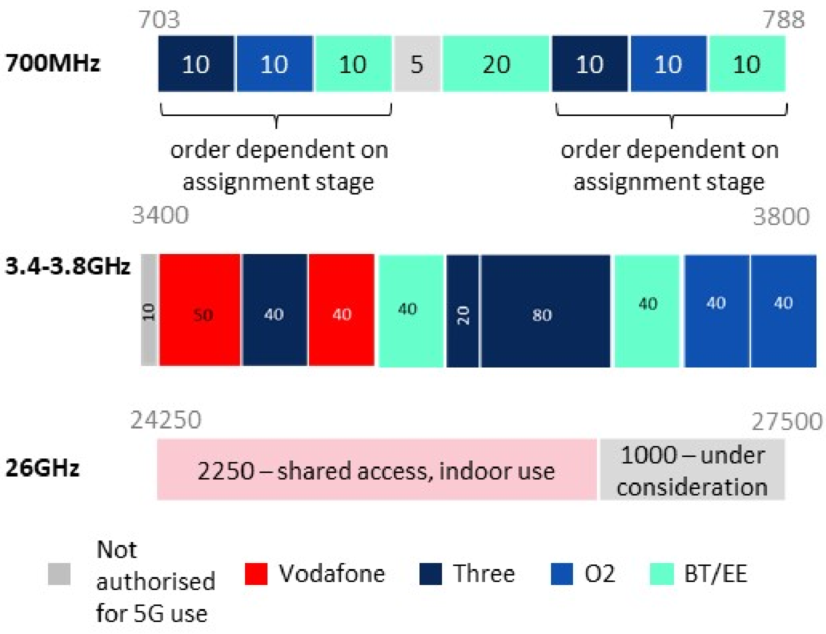


Source: Ofcom, Analysys Mason.

In some other European markets, MNOs also have access to spectrum in the 26GHz band for 5G use. In the UK, the lower part of the 26GHz band is reserved for private and shared access and is currently available on a shared access basis, restricted to indoor use. Ofcom has not yet published a licensing framework for 5G outdoor use of the 26GHz band.

The current state of 5G spectrum assignments, including recent awards of 700MHz and 3.6-3.8GHz bands are presented in Figure 4-3, although the order of recent assignments is still to be determined.

Figure 4-3: Map of 5G pioneer spectrum bands in the UK following March 2021 spectrum awards (MHz)



Source: Ofcom, Analysys Mason.

4.3 Spectrum for private 5G deployment

MNOs' slow implementation of the latest functionalities into public networks might stimulate demand for private 5G networks

Private 5G deployments are an alternative to using a public mobile network for 5G service delivery, suitable especially for businesses or industrial customers who may wish to tailor coverage, capacity and/or services to their specific needs. These private 5G deployments might be used by several of the 5G consumer groups discussed in this report. There are multiple reasons why some industrial users or businesses might choose to deploy their own 5G infrastructure rather than using a public mobile network, but a key reason would be to ensure that the 5G technology capabilities that specific companies need are provided in the timescales those companies require. One reason for this is that these bespoke 5G capabilities might not be available in public mobile networks, as MNOs are unlikely to implement the most recent 5G functionalities into public networks at scale until there is sufficient market demand to do so.

Ofcom has taken steps to support the deployment of private 5G networks via shared access spectrum

If bespoke functionality of 5G is unavailable from public mobile networks deployed by MNOs, or if users prefer to make use of a dedicated, on-site network for their own business use, there is emerging evidence – such as from published articles and reports of trials[10] - of interest in deployment of private 5G networks to fill this gap. 5G private networks are now emerging in the UK and several other markets, tailored to delivering the specific use cases and functionalities required by specific enterprises and industries. These private networks might be used by firms whose central business is not

[10] For example, https://www.lightreading.com/5g/vodafone-partners-with-ford-to-deploy-private-5g-network-in-uk/d/d-id/761965

telecommunications, such as certain small and medium-sized enterprises (SMEs) in the industrial sector. These firms might have a need for tailored 5G coverage and/or capacity to meet specific business needs. Recognising that some enterprise or industrial users of 5G might wish to deploy their private networks in the shorter term, Ofcom has taken proactive steps in the UK to encourage private 5G deployment by making spectrum available via a local licensed, shared access, framework. Shared access licences are technology neutral and can be used for local 5G network deployment. These private networks can be deployed either by MNOs, or by third-parties.

Spectrum in two bands has been made available on a local basis suited to private 5G use

For private 5G networks, Ofcom has made available spectrum in two bands supported by 3GPP specifications for 5G devices – firstly the lower 2.25GHz of the 26GHz band has been reserved for private and shared access for indoor use across the UK, available for 5G use[11], and secondly the 3.8-4.2GHz band (a total of 400MHz) is available on a shared use nationally, where other existing users have not deployed[12]. The availability of the 3.8-4.2GHz band (adjacent to spectrum used by the public 5G networks, and supported by 3GPP equipment) on a shared use basis is intended to enable deployment of 5G infrastructure for prospective enterprise or industrial users[13]. The 3.8-4.2GHz band is part of the 3GPP ‘n77’ band (which spans 3.3-4.2GHz) and hence devices supporting band n77 will be compatible with use in the 3.8-4.2GHz band. Industrial users themselves, or their network delivery partners (including MNOs) can apply to use Ofcom’s 3.8-4.2GHz spectrum for deployment of dedicated networks and for MNOs, this might offer an easier route to provide early industrial 5G services, until the public 5G networks have capabilities for network slicing and quality of service (QoS) tailoring. It is noted the spectrum assigned to MNOs in other 4G/5G frequency bands can also be used for local deployments. Ofcom publishes details of the local licences it has issued[14].

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[11] Ofcom manages and facilitates access to this spectrum on a per-location, ‘first-come, first-served’ basis, allowing users to apply for a licence for as many indoor base and terminal stations needed to cover a circular area with a maximum 50-metre radius. “By enabling access to the lower 26 GHz band, we are adding to the spectrum options that would enable deployment of new 5G indoor applications, for example for industrial users, with little to no impact on existing services and without prejudicing any future use of the band outdoors.”

[12] The 3.8-4.2GHz band is part of a spectrum band allocated for fixed satellite service (FSS) use internationally, and was also used for fixed links in the UK. The limited deployments by existing incumbent satellite and fixed users in the UK means that shared access is feasible, and available across most of the country.

[13] The spectrum is available across the country, though there are exclusion zones in certain areas for satellite earth stations. There are two types of licence – a lower power licence (potential uses: industrial and enterprise private networks and/or indoor mobile coverage extensions) and a medium power licence (potential uses: industrial users with distributed sites, like ports, railyards, or large factories, and rural FWA). Applications are currently open; Ofcom will assign local licences to people for coordinated access to this band on a “per location, first come, first served” basis. Fees are payable, and if mobile terminals are deployed licensees must keep an accurate record of the address they are limited to operate within.

[14] Local Access licences (ofcom.org.uk)

Ofcom is making it easier for local users to access spectrum that is not being used

Ofcom has also introduced an approach whereby local users can apply to access spectrum that is already licensed to MNOs but not being used or planned for use within the next three years in a particular area[15] (Ofcom 2019). Again, this is aimed at accelerating local infrastructure deployment and deployment of private 5G networks where MNOs are not using the spectrum to provide services within their public networks.

Several other European regulators have also taken steps to enable private 5G deployment

In Germany, the Federal Network Agency, Bundesnetzagentur (BNetzA) has reserved spectrum available for private 5G deployment in the 3.7–3.8GHz band. In March 2019, BNetzA published a framework for local 5G applications in this band; applications were opened in November 2019. The private spectrum licences are awarded on a local basis and used for “innovative 5G local solutions” in the industrial or small business sectors. Subsequently, in January 2020, BNetzA published the process for making the 26GHz band available for 5G use in Germany. In Germany, spectrum from 24.25-27.5GHz is being made available on a ‘first-come, first-served’ licensed basis intended for localised usage. Spectrum is being licensed in multiples of 50MHz blocks, and can be used for any form of 5G connectivity including to provide wireless broadband (fixed wireless access), mobile broadband, and industrial / IoT connectivity (Bundesnetzagentur 2021). The regulator in Finland has also reserved spectrum in the 26GHz band for industrial 5G use.

In France, MNOs must provide customised solutions to enterprises and businesses or assign their frequencies locally to a provider who can

In France, the four nationwide MNOs agreed to make optional commitments to accelerate infrastructure roll-out, in exchange for 50MHz blocks of 3.4GHz spectrum in the 2019 auction. One of these commitments was to commit to “granting reasonable requests from economic actors (business, local authorities, administrations…) by providing them with customised solutions in terms of coverage and performance or, if the operator prefers, by assigning its frequencies locally”. Additionally, applications for frequencies in the 2570-2620 MHz band were opened to metropolitan businesses by the regulator ARCEP in May 2019 (ARCEP 2021). Applicants are granted spectrum through an online portal which has been open for applications since May 2019 (European 5G Observatory 2020).

In the UK, a faster application process for a 5G private network licence would help

Speed of the licence application process is likely to be important to ensure that private 5G networks can meet immediate industrial needs. We understand that Ofcom may look to explore the options of an online application process to speed up the application process for shared access licences in the 3.8-4.2GHz band.

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[15] Provided Ofcom and the incumbent licensee agree that the new user is unlikely to interfere with the incumbent’s network or constrain their future plans, Ofcom will issue a short term (default of three years) local access licence.

Greater harmonisation across Europe on spectrum bands for private networks may improve the economics of private network deployment

A June 2021 publication from the European Commission's Radio Spectrum Policy Group (RSPG) recommends that European regulators consider use of the 3.8-4.2GHz band for 'local vertical applications', which will potentially improve the supply market for equipment in this band if more European regulators pursue this option[16]. In June 2021, the Norwegian regulator Nkom proposed to open up the 3.8-4.2GHz band for local 5G networks, which will align with the spectrum already available in the UK. However, in markets such as France and Germany, different bands are already being used for local 5G deployment (2.6GHz in France, and 3.7GHz in Germany). The lack of a fully harmonised private network solution is likely to have cost implications on 5G devices (e.g. modems, transmitters, sensors) and new proofs of concept. This consideration would apply particularly to industrial use cases and firms operating in different European geographies where tailored devices would be required to support different spectrum bands.

4.4 Network architecture

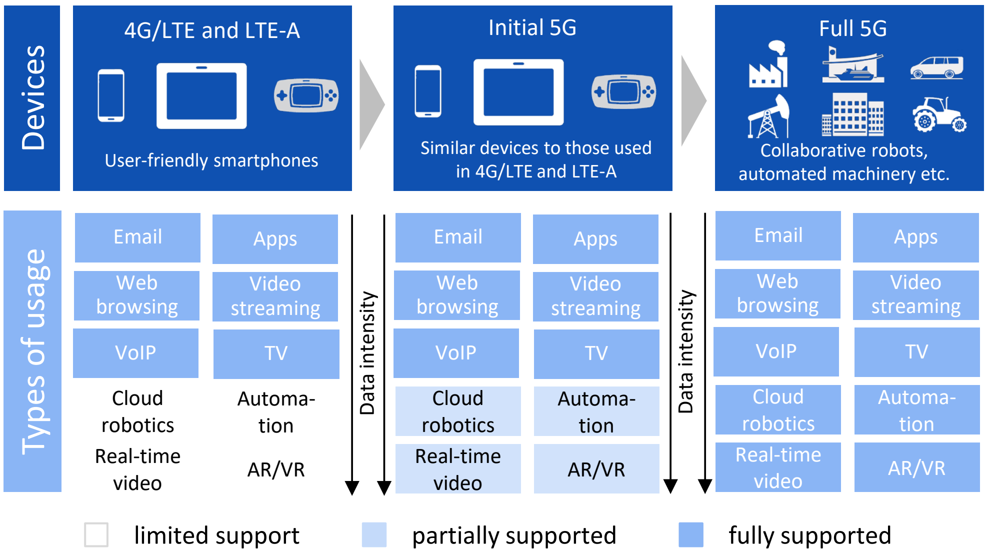
5G networks can be delivered on standalone and non-standalone architectures

Industry reports such as the Global Mobile Trends report from GSMA Intelligence (2021) highlight the enterprise opportunity for 5G, for which there are several deployment options. There are two main 5G architectures – non-standalone, and standalone – with several options in terms of how each of these can be deployed.

Standalone networks are important for realising the enterprise opportunity

As indicated by the GSMA Intelligence report, the enterprise/business opportunity is predicated on the availability of 5G standalone (SA) networks, which are able to offer lower-latency capabilities than earlier technologies or 5G when delivered via non-standalone infrastructure. This is because standalone (SA) architecture is expected to unlock the more advanced technical functionalities of 5G, such as the ability to tailor quality of service through customised, end-to-end virtual network slices meeting different user requirements such as low-latency, ultra-reliable use cases (see Figure 4-4).

Figure 4-4: Mobile traffic and usage evolution with 5G SA architectures



Source: Analysys Mason.

[16] RSPG21-024final_RSPG_Opinion_Additional_Spectrum_Needs.pdf (rspg-spectrum.eu)

Standalone networks operate independently of 4G and enable operators to offer more bespoke solutions

From an infrastructure perspective, the evolution from a non-standalone (NSA) 5G services to 5G SA involves migrating 5G networks to use 5G radio and core networks operated independently of 4G. The prospect of 5G core networks being cloud-native also helps with enabling enterprise or industrial users to deploy their own 5G private networks, as well as improving the flexibility in public networks to offer differentiated services to business or industrial users.

Several options exist for the deployment of standalone enterprise networks

5G SA enterprise networks might be delivered using public mobile networks and using the spectrum licensed to individual MNOs. Alternatively, private 5G deployment might present a better opportunity for some enterprise or industrial users, utilising the 5G local licences in the 3.8-4.2GHz, and/or in the 26GHz band (indoor use only), as described in the previous section.

The majority of a network may be software-driven but migrating and integrating solutions will still be complex

Due to the increasing implementation of software-defined network architectures both 5G infrastructures and devices could be developed to include incremental features as and when the demand arises. Developments by many leading vendors suggest the majority of a network will be software-driven and as such new functionalities should only require a software upgrade (if the demand and business case are evident for MNOs and vendors). However, in the short term as virtualised solutions are starting to emerge, the complexity of migrating, and integrating, solutions is a key issue. It is noted DCMS is funding the SmartRAN Open Network Interoperability Centre (SONIC) and an Open RAN test bed to assist in ecosystem development for interoperable solutions.

4.5 3GPP standards and releases

It takes time for new 3GPP-based functionalities to be integrated into networks and devices

5G network capabilities (latency, service-specific network slicing, quality guarantees and support for different device types, amongst other requirements) depend on specific functionalities being implemented in the 5G core and radio networks, and for users to adopt the latest devices. While these network and device functionalities are standardised by the industry based on 3GPP releases[17], there is typically a material lag between new releases being finalised by 3GPP and fully tested products being available and adopted, both in MNO networks and in the devices available to consumers. The path from release to deployment follows four key stages: standards approval (e.g. 3GPP release 16 or 17); integration into vendor solutions; validation and commercial availability and finally, deployment/adoption.

The integration of functionalities and the availability of reliant use cases will likely be sporadic

The most advanced 5G use cases are reliant on the latest 5G standards and functionalities, which will become available in waves, depending on when 3GPP specifications are completed and when such specifications are implemented in network equipment and devices. It is typically the case that there is a time lag of between twelve and eighteen months between a specification being studied in 3GPP and it being implemented by vendors (for examples of the time for 3GPP studies to be completed into Release 16 and 17 features and for these specifications to be finalised and ready for

[17] 3GPP is a collection of standards organizations that develop standards for telecommunications technologies. Standards are released in waves called “releases”, and each release will contain hundreds of individual technical standards.

implementation by vendors, see Figure 4-5). Not all vendors will implement all 3GPP optional features and some features might not be implemented by any vendor.

The implementation of future 3GPP features and functionalities will depend on demand and cost

UK MNOs have deployed their public mobile networks using the versions of 3GPP equipment that the MNO procured for network launch (likely to be 3GPP Release 15 and Release 16 at the time of producing this report). For 5G features and functionalities standardised within future 3GPP releases (e.g. Rel17 and onwards[18]), implementation into networks is dependent on demand. Not all functionalities of every 3GPP release are implemented at the same time or available in every market. Features may be present in vendors' 'base build', but it is up to the operator to implement it (and this might involve additional costs).[19]

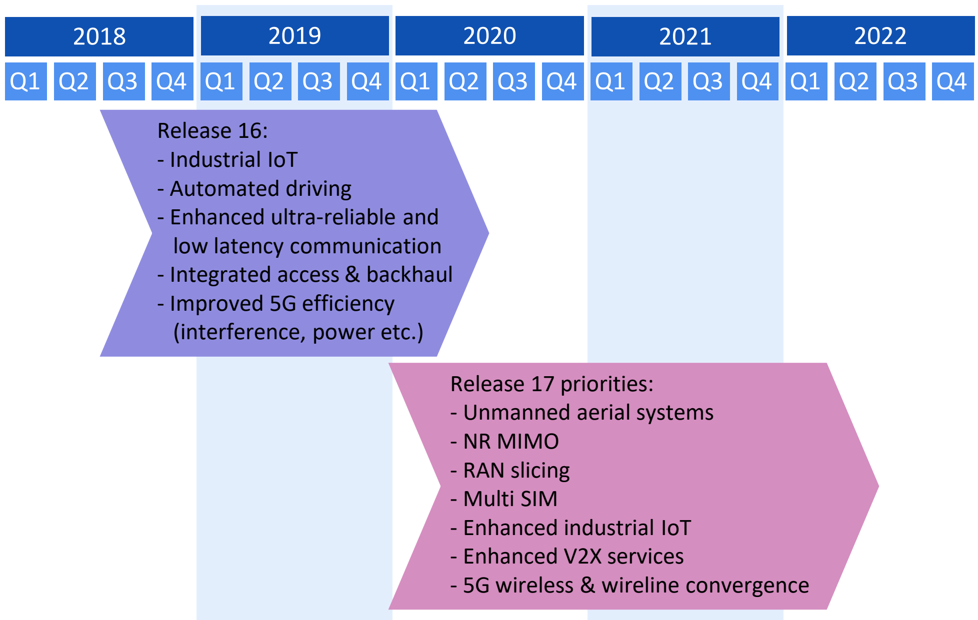
Many new features and functionalities will rely on the deployment of standalone networks

Full exploitation of new features and functionalities described within Rel17 and beyond will rely on evolution of initial 5G networks to deployment of 5G SA infrastructure. This 5G SA infrastructure is important because in 5G SA, the 5G core network is virtualised and not dependent on 4G networks. It is also expected that 5G SA virtualised networks will use software implementation that is cloud-natively designed, such that enterprises or industrial users already using cloud-based business processes might integrate 5G deployment with these designs .

The pace of transition to standalone networks will dictate when more advanced 5G applications become available

As MNOs are still planning the transition from NSA to SA architectures, MNOs' implementation of some 5G capabilities – which may be required for some of the more advanced 5G use cases – will be dependent on the speed at which this transition is completed, as well as on 5G SA device penetration. Hence, some of the more advanced 5G applications that industrial or enterprise customers might use to enable new and improved business processes might not be immediately available via public networks.

Figure 4-5: 5G capabilities included in 3GPP Release 16 and 17



Source: 3GPP, Analysys Mason

[18] 3GPP has commenced discussions into what features might be included in Release 18, but a timeline for developing Release 18 specifications is not yet available.

[19] As noted by vendors in the DCMS stakeholder workshop

MNOs' longer transition to standalone means a role for private networks in the early delivery of some 5G features

5G SA deployments are occurring in the enterprise and private wireless space as described in the previous section, and these are being trialled extensively[20] already. The 5G SA transition within public mobile networks is more complex where and demands evolution of devices as well as network equipment and hence is expected to have a longer timescale. As such, private networks are likely to play a role in delivering some 5G features and enable some 5G consumer groups (e.g. enterprises, factories) to adopt 5G earlier in the 5G deployment cycle.

The prospects are for future 5G specifications to be more numerous and complex

5G specifications will continue to evolve beyond the currently planned releases shown in the diagram above. At the time of producing this report, the priorities for 3GPP Release 18 have not been finalised by 3GPP. Mobile equipment vendors are also proposing to expand 5G from the three original deployment scenarios – enhanced mobile broadband, massive machine-type connectivity and ultra-reliable, low latency communications – to include three additional deployments – uplink centric broadband communication, real-time broadband communication and harmonised communication and sensing. Some equipment vendors are also suggesting a further generation of mobile connectivity – 6G – occurring sometime after 2030.

4.6 Readiness to deploy and adopt 5G in the UK

Cross-country studies provide a comparative assessment of countries' readiness to deploy 5G

While the roll-out of 5G in the UK and other countries is in its early stages, there are some cross-country studies that provide a comparative assessment of countries' readiness to deploy and adopt 5G. These readiness reports often evaluate readiness to adopt 5G between markets based on scoring different factors, such as availability of infrastructure, 5G pilots and test-beds, spectrum availability, policy framework and other such factors. The findings from these studies are summarised in Table 4-1.

5G readiness in the UK is reasonably high and the UK is a leader in the adoption of public cloud and AI

Comparing the UK to other international markets where digital adoption and transformation is expected to be highest, i.e. countries within developed Asia Pacific, leading Western Europe economies (France, Germany, Switzerland etc.) and the USA (with full details set out in standalone Appendix C):

- The UK typically ranks highly on 5G readiness compared to other markets, but behind market leaders including the US, South Korea, China and Japan.
- The UK appears to sit amongst the leaders of benchmarked countries with regards to public cloud adoption in firms.
- Similarly for AI, the UK was shown to be an earlier adopter within Europe.
- However, in terms of IoT and robotics and automation, evidence presented places the UK behind leading digital economies.
- While some indicators around government-led efforts to spur automation adoption are positive for the UK (i.e. ranking 8th globally in the Automation

[20] Trial kits vary by operator – for example this solution from Ericsson was mentioned https://www.ericsson.com/en/news/2020/6/ericsson-5g-sa-trial-kits-for-industry

Readiness Index), implementation of industrial automation and robotics is lagging and has dropped below the international average.

Table 4-1: Third party studies on UK 5G adoption – 5G readiness

Study	Sources of analysis	Findings
Moving to a fibre-enabled UK: International experiences on barriers to gigabit adoption (WIK 2020)	Comparative study – categorising UK relative to France, Germany, Italy and Sweden	UK consumers are "relatively advanced when it comes to demand for digital services": for "demand for bandwidth […] the UK came close behind Sweden, a global leader in connectivity and digitisation". However, "the UK is behind Sweden in the development and usage of other applications which could necessitate gigabit connectivity in the home and for small businesses"
Europe 5G Readiness Index (inCites Consulting 2019)	Comparative study – categorising UK relative to other markets in Europe. Ranking was based on the following criteria – infrastructure and technology, regulation and policy, innovation landscape, human capital, country profile and demand	The UK placed sixth overall in Europe in this 5G readiness index, but with the highest score (5th) for infrastructure and technology. On selected other criteria, the UK was ranked lower than European counterparts, such as innovation and landscape, and human capital.
5G Market Progress Assessment (OMDIA 2020)	Study ranking countries by available spectrum, service provider launches, network coverage, 5G take-up and ecosystem	The UK was sixth globally for 5G deployment – behind South Korea and Switzerland, as well as the USA, Kuwait, and Qatar.
Global race to 5G update (Analysys Mason for CTIA 2019)	Study ranking countries by available spectrum, industry activity (trials, pilots, network launches), availability of mid-band spectrum, availability of high band spectrum, total spectrum release and Government 5G commitment (strategies, funding, testbeds etc.)	The UK was ranked 5th in this report published in 2019, out of a total of 14 selected countries. The top four countries were China, USA, South Korea and Japan.
The Race to 5G (Arthur D. Little 2019)	Study ranking countries by infrastructure drivers (5G spectrum availability, 5G roll-out commitments, fibre coverage, 4G availability etc.) and commercialisation drivers (5G trial intensity and successes, fibre household	The report identified eight countries leading the "5G race" and four fast followers (the first being the UK) out of 43 countries. "The UK [is] in a situation in which their regulator recently auctioned spectrum and operators jumped to acquire it. They are well advanced in terms of trials and face competitive pressure to roll

	penetration, household income, 4G usage etc.)	out their 5G networks but rank lower in some infrastructure dimensions."

Source: As listed.

The willingness of UK firms to invest in 5G is not universal due to some potential barriers to adoption

In addition to the country studies, other survey-based studies provide insights on the attitude of UK businesses towards 5G and their willingness to invest in 5G. The results of these studies are summarised in Table 4-2.

This shows industrial companies in the UK being positive towards taking up 5G solutions, with a willingness to implement in the short term. However, whilst some evidence indicates a willingness of UK businesses to take up 5G solutions, this finding is not universal. For example, some published studies identify potentially significant barriers to 5G adoption in the UK, such as a lack of willingness to pay, investment uncertainty and a lack of awareness and understanding of 5G and its potential benefits (Barclays 2019).

Table 4-2: Third party studies on UK 5G adoption – UK industries

Study	Sources of analysis	Findings
5G in industrial operations (Capgemini 2019)	Interviews – results broken down by country, sub sector or company revenue size.	• 75% of UK organisations are willing to implement 5G for operations within two years of availability (23% within one year of availability, and 52% between 1-2 years of availability). This is on par with Italy, and better than Spain, the USA, Norway, France, Sweden, South Korea and Germany. • Of all industrial companies surveyed, 66% of all automotive companies were willing to implement 5G for operations within 2 years (28% within one year, 38 in 1-2 years). Utilities was 69% (26:43), Airport, port and railway was 70% (10:60) etc. • As revenue size increased so too did share of companies planning to implement 5G within 2 years of availability.
GWS survey (GWS May 2020)	GWS polled both 2000 UK adults and more than 200 enterprise organisations ranging in size from 100 employees to more than 5000.	• Awareness of 5G is strong, even if it is in early days of deployment in the UK. More than half of the businesses polled reported that 5G is "already important to their organisation," with another 27% saying it will be so in the future. In addition, 26% of businesses said they wanted to see more 5G offerings from their mobile network operator.

Source: As listed.

4.7 Digital investment propensity assessment

Since 5G rollout is still being scaled up in the UK and other countries, there is a lack of empirical evidence on the adoption of 5G across the different consumer groups. For the purposes of further analysis and modelling, we have investigated the uptake of other digital technologies by sectors within the identified consumer groups, to provide a benchmark of how likely different sectors/groups might be to adopt ‘new’ technology.

We have defined this analysis as a ‘digital investment propensity assessment’, as a means of considering how likely different UK sectors are to adopt 5G services based on wider digital technology adoption in those sectors.

The assessment uses historical adoption of selected alternative advanced technologies as an indicator of which consumer groups may have higher willingness to take up 5G solutions. Whilst this digital investment propensity assessment does not provide distinct 5G adoption targets or metrics for consumer groups, it has assisted in gathering insight into the rate at which consumer groups are likely to adopt 5G services in the early years, as well as some indication of the consumer groups that are likely to be early adopters of 5G. The findings of this assessment have been used to rank digital investment propensity across UK economic sectors which was further mapped onto our consumer groups and used to calibrate modelled 5G adoption forecasts covered in chapters 6 and 7.

The first piece of analysis looked to prioritise which sectors within the UK economy spend and invest the most in digital technology. Secondly, this prioritisation was cross-checked through analysis of historical adoption trends for other advanced technologies by various industries (either globally or UK specific) or for the UK as a whole. A supplementary input to this assessment was consideration of the UK’s current position on digital and 5G adoption.

Summary of findings

Three consumer groups have high digital investment propensity

From our nine 5G consumer groups, we have identified three groups as having the highest intensity of digital investment and intermediary consumption (it is noted that investment intensity is not universal across all sectors in a consumer group but based on the evidence available, we have assessed technology adoption at the consumer group level rather than specifically for each sector within a consumer group):

- Media and entertainment
- Smart urban
- Public services

Rurally-located firms in high-tech industries might lag on adoption

Additionally, high technology industries generally (e.g. IT industries) are high adopters of technology such as cloud). Most of these high-tech industries are located in areas of the UK that might be assumed to be within the population-led coverage of nationwide MNO 5G roll-outs. However, these industries, if operating in rural locations, might lag on adoption of 5G specifically due to delayed coverage roll-out, patchy coverage or a lack of coverage.

Different sectors are adopting different technologies

From the digital investment propensity assessment that we conducted as part of this study, it is clear there is variation between the types of digital technology that different sectors are adopting:

- UK sectors within media and entertainment, smart urban and public services consumer groups have a high-level of cloud service adoption
- Industries within the smart urban consumer group (e.g. financial services and high tech industries) are identified as early adopters of AI solutions. Emerging sectors indicating an interest in future AI spend or have already made some investment in AI, include those within the Transport, Manufacturing, Energy and utilities and Media and entertainment consumer groups.
- Transport and manufacturing sectors have shown an appetite to adopt IoT networks and are likely to benefit from the capabilities 5G-based IoT will offer once this is available, e.g. high density capabilities and real time IoT use cases (e.g. asset management, production lines, delivery and logistics tracking, drones and surveillance). Other emerging industries that have shown an appetite for IoT fall within the smart urban sector
- The manufacturing and automotive industries are also likely to have the highest propensity to adopt automation and robotics associated technologies
- The retail and hospitality group generally lag on digital adoption

The UK is leading in some technologies and lagging in others

The assessment also considered the UK's global position in terms of adoption of digital technologies. The UK was founding to be leading in adoption of some technologies but lagging for others:

- Evidence from Eurostat suggests that the UK compares well against the wider EU market on cloud adoption (Figure C.3 and Figure C.4). 2018 metrics published by Eurostat (Eurostat 2020), show that at least 40% of enterprises in UK, Ireland, Finland, Sweden, Denmark, Belgium and the Netherlands made use of cloud computing solutions. However, on an EU-wide level this drops to 26% of enterprises, largely for email hosting and file storage.
- North America is leading in real-world implementations of AI in operation, with Europe and Asian companies also reporting strong AI initiatives. It is reported that UK is leading within Europe when it comes to AI adoption, where about a fifth (18%) of the UK companies have stepped into the most advanced stage of AI maturity (Business Leader 2021).
- According to Vodafone's IoT Barometer (Vodafone 2019), companies in the Asia–Pacific region are advanced in their adoption of IoT, and 43% of companies are already using some form of IoT. Across Europe, the Middle East and Africa, there has been a levelling out of IoT adoption since 2015, falling behind the global average.
- A report conducted by IFR (IFR 2020) found that, in terms of robot density by region, China, Japan, USA, South Korea and Germany

have been the top five markets for adoption since 2016. The UK appears to be lagging significantly behind leading digital economies in industrial robotics adoption and continues to drop below the international average. In 2019, around 21,700 industrial robots were operating in factories in the UK, an increase of 5% compared to 2018. Although the UK´s operational robotics stock has increased, other European countries like France, Italy and Germany have seen an increase in robot stock in operation of 2-10 times.

The assessment provided limited evidence on propensity for rural industries to adopt digital technologies. We also excluded the high-speed broadband in homes and offices consumer group from our digital investment propensity assessment, on the basis that high-speed broadband is the basis of early 5G deployment by MNOs, for which adoption can be tracked in the same way as for previous generations of mobile use (i.e. based on growth in number of 5G connections, 5G subscribers or similar).

Table 4-3: Digital investment propensity assessment summary

Consumer group	Cloud	Automation and robotics	IoT	AI
Media and entertainment				
Public services				
Energy and utilities				
Rural industries				
Smart urban**				
Transport		*		
Manufacturing, logistics and distribution				
High-speed broadband into homes and offices				
Retail and hospitality				

* for the automotive industry specifically

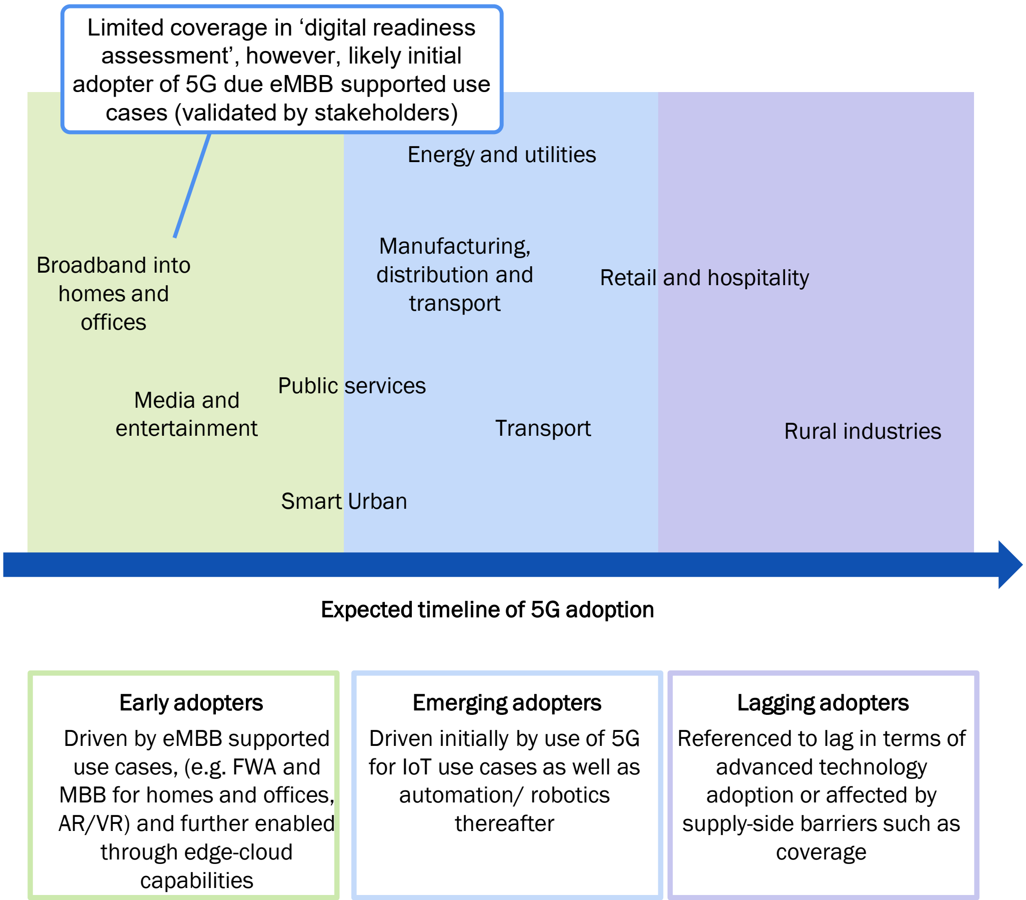
** for high tech industries and smart cities specifically

Early adopter | Emerging adopter | Lagging adopter | Limited evidence of adoption | Limited evidence overall | Excluded from digital readiness assessment

Source: Analysys Mason

From this analysis we have concluded there is evidence that sectors within most 5G consumer groups are early adopters of digital technologies. From this, we mapped potentially early, emerging and lagging adopters of 5G services in the UK based on their adoption of digital services (see Figure 4-).

Figure 4-6: Timeline of 5G adoption by consumer groups in the UK



Source: Literature review, Analysys Mason.

We subsequently used this map of relative timeline of adoption per consumer group to calibrate 5G adoption forecasts and scenarios forming an input to the benefits modelling (how the 5G adoption forecasts have been defined is further outlined in chapter 6).

5 Barriers to adoption and their impact

This section describes and discusses the key barriers that might affect 5G adoption in the UK, and also how we might reflect the impact of these barriers within the adoption forecasts developed from the study.

5.1 Approach

To identify the barriers to 5G adoption and assess their impact, we conducted a detailed review of the literature and our own analysis. This was supported by discussions with the DCMS team and 5G stakeholders. We began by consulting the literature on 5G adoption and barriers in a range of countries and for a wide range of consumer groups. The findings from this review were used to identify a high-level typology of the barriers to 5G adoption. Using these initial categories of barriers, we developed specific questions on what the key barriers to adopting 5G might be in the UK market. These were used to gather feedback from stakeholders through interviews and an industry workshop. In discussion with DCMS, questions on UK-specific barriers were split into demand-side, and supply-side, barriers. The responses on barriers were summarised and, along with further analysis, the barriers to 5G adoption in different consumer groups was further refined and developed to reflect the most relevant to consumer groups in the UK.

5.2 Overview of the barriers to 5G adoption

While the focus of this study is on 5G demand, both supply-side and demand-side barriers were reviewed to build an overall picture of the barriers to adoption. Supply-side barriers were found to fall into three categories: business case/value concerns; practical deployment barriers; and spectrum-related barriers. Likewise, demand-side barriers were grouped into three categories: business case/value concerns; feasibility; and (technical) criticality. To analyse the relevance of each demand-side barrier to the consumer groups, we further divided these barriers into macro barriers and micro barriers, using the below definitions:

- **'macro barriers'** were defined as cross-market barriers that cut across multiple areas / consumer groups and 5G applications across most of the 5G market.
- **'micro barriers'** were defined as barriers that apply more to some consumer groups / 5G applications than others, but can be grouped into distinct general categories, e.g. device availability.

An overview of the barriers resulting from our analysis is provided below in Figure 5-1 and Figure 5-2. Section 5.3 provides a discussion of the barriers, Section 5.4 discusses the impact of the demand-side barriers on each consumer groups, while detailed summaries of the evidence behind each barrier is provided in Section 5.5 and Section 5.6.

Figure 5-1: Supply-side barriers

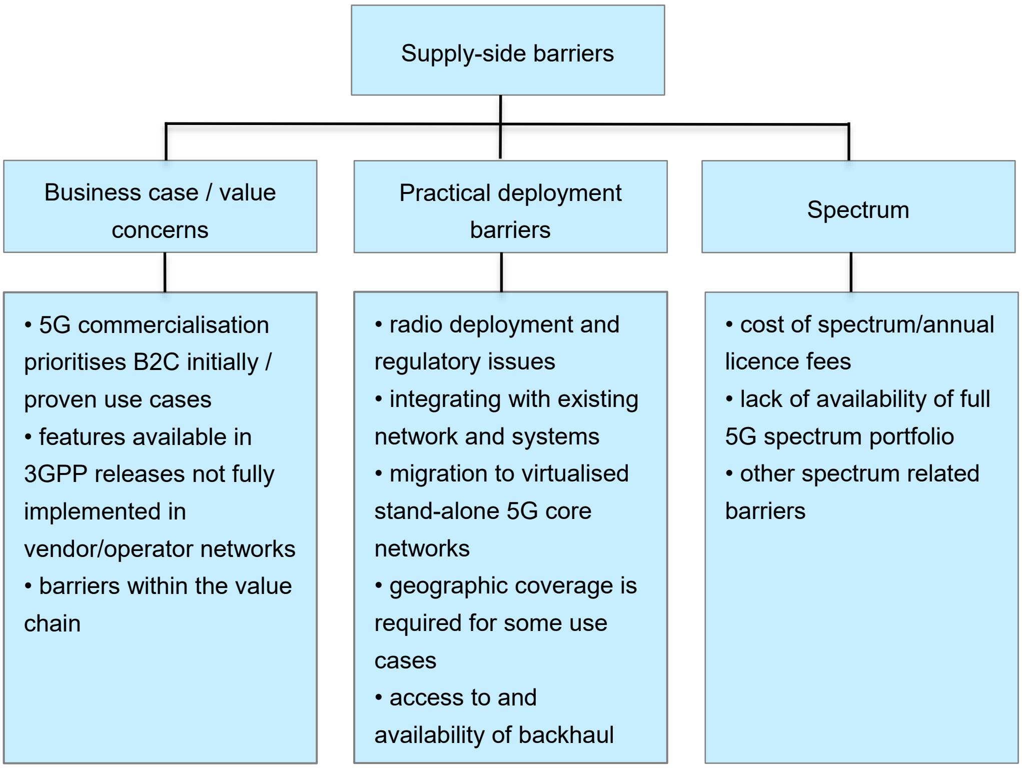
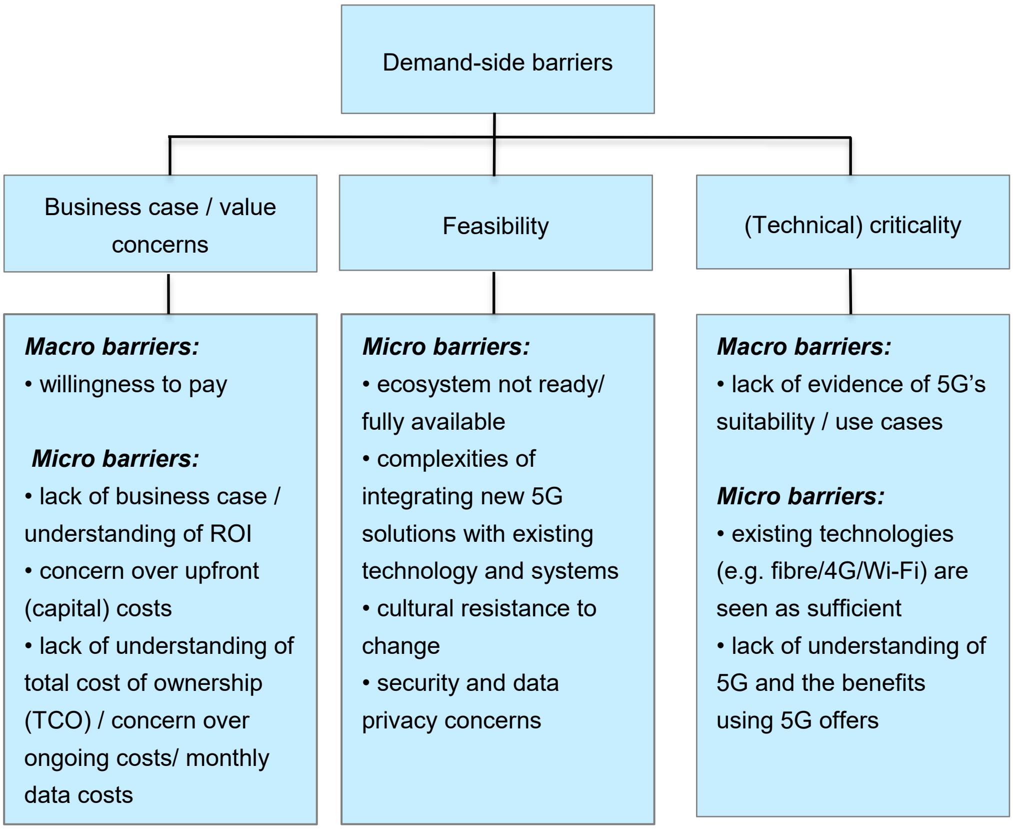


Figure 5-2: Demand-side barriers



5.3 Barriers to 5G adoption in the UK

This section presents a discussion of the demand-side and supply-side barriers, drawing on the findings from the literature review and other evidence presented to us during the study.

Supply-side barriers

Absence of a clear business case by MNOs to invest at scale limits coverage and available functionalities

A key type of supply-side barrier is concerns over the business case for investment, resulting in a lack of further investment in 5G coverage from public mobile networks, and a lack of a full range of 5G functionalities in public mobile networks to enable specific use case deployment requiring the latest 3GPP functionality. MNOs and vendors need a clear business case to underpin further investment in 5G public mobile networks (both coverage and full functionality features of 5G). In some cases, demand needs to be demonstrated at scale across the UK, from different regional or local users – e.g. for transport systems, for operators to invest in fully interoperable and scalable solutions.

The business case for investment is undermined by a 'chicken and egg' problem

How MNOs might develop additional revenue from deploying 5G for consumer use is currently not clear. Whilst new revenue streams could be generated from offering advanced use cases to other consumer groups, the business case for this additional investment is unclear, as identified above. Trends in 4G adoption suggest that whilst data consumption by individual consumers using smartphones and other connected devices has grown considerably (and continues to rise), average revenue per user (ARPU) from individual consumers is either flat or declining in many markets. Whilst 5G roll-out will require significant investment by MNOs, demand from new consumer groups (e.g. industrial or enterprise) is still emerging. It is these new consumer groups that might demonstrate greatest demand for advanced 5G use cases such as automation, 5G-based robotics and advanced, 5G-based IoT, but this would only emerge once users are confident that 5G solutions meet their specific requirements. Demonstrating that solutions meet requirements for industrial and enterprise users is complex because individual organisations might require bespoke functionalities relevant to their specific applications and locations, and/or will have specific coverage and capacity requirements for their solutions, which might not match the population-drive infrastructure rollout that MNOs have planned for 5G consumer use. This 'chicken and egg' problem of 5G use cases i.e. the need to build infrastructure supporting unknown use cases and/or uncertain assumptions on how users might use 5G technologies in future, presents a key risk both for MNOs, and for potential 5G users. A major consequence of this 'chicken and egg' problem is that relatively few large business users might be willing to invest in 5G solutions if this investment is 'at risk' (i.e. ahead of assurance that 5G will meet specific locational/application needs). This may require the MNOs to take on more of this investment risk. Conversely, the MNOs might find it hard to justify this investment until it is clearer how new 5G use cases will manifest (i.e. in which areas, as well as other specific connectivity needs). It is possible that this issue might be overcome over time as consumer 5G use migrates from current NSA devices to using 5G SA devices. Once SA devices are adopted over time by consumers, this might drive adoption of 5G SA features more generally (e.g. by enterprise and industrial users). Over time, this 5G SA adoption would therefore incentivise MNOs to invest in more widespread implementation. An alternative way for MNOs to encourage enterprise and industrial adoption of 5G would be to subsidise the 5G consumption (e.g. outcome-based type contracts).

There is some doubt about the pace of MNOs 5G roll-out

There is some scepticism amongst some potential 5G users over the pace at which MNOs will invest in extending the capabilities of public mobile networks. As such, MNOs need to be positioned as active enablers of the most advanced 5G services, moving beyond the early and most feasible business cases of 5G services offered to existing subscribers. As mentioned previously, the market is yet to become familiar with offering the sorts of differentiated enterprise and vertically-focused solutions that fully functional 5G (including virtualised standalone core networks and network slicing) envisages.

5G private networks may be the best option for early industrial adopters

Given a general uncertainty over timescales for further evolution of public mobile networks towards full enabled 5G features (i.e. including 5G-based machine-type connections and ultra-reliable, low latency communications as per the original 5G vision), some potential 5G users (and indeed MNOs) might feel that 5G private networks may be better placed to serve earlier adopter industrial and enterprise users. The specific connectivity needs of those customers would be a key reason for using private deployments given that in current non-standalone 5G public network deployments, there will be challenges in offering differentiated connectivity with different characteristics in some areas of the network compared to others due to the risk of interference. Therefore, utilising shared access spectrum in the 3.8-4.2GHz band rather than using the MNO's nationally available spectrum portfolio enables MNOs or other providers to provide specific connectivity such as uplink-oriented capacity where needed.

There are various practical deployment barriers on the supply-side

A number of practical barriers to mobile deployment are widely discussed in published reports, and well known to DCMS through work contributing to the digital connectivity portal[21]. Several studies present evidence for practical deployment barriers such as relating to site acquisition, backhaul, power and other infrastructure availability, and fibre reach (Infosys 2019; Analysys Mason 2018; OECD 2019; Nokia 2020).

Spectrum concerns, such as availability and cost, are also barriers to supply

Timely deployment of 5G depends on suitable spectrum being available for the different types of potential network/user. In the UK, commercial nationwide 5G networks providing 5G services to consumers are using the 3.4-3.8GHz spectrum available to MNOs together with other spectrum bands that MNOs have been licensed to use. Private or local 5G deployments in the UK are being enabled through Ofcom's shared access spectrum available in the 3.8-4.2GHz band. During course of this project Ofcom awarded 700MHz and 3.6-3.8GHz spectrum to UK MNOs in March 2021. Both of these bands are suited to 5G use. As such we do not expect spectrum availability for nationwide 5G network deployment by MNOs to be a significant barrier to 5G adoption in the UK. Ofcom's shared access licences also allow for private 5G network deployment, on a local basis.

[21] Digital Connectivity Portal - GOV.UK (www.gov.uk)

Different spectrum bands for private networks hinders economies of scale

There are different approaches to 5G private/local licensing across different markets in Europe. Lack of a common spectrum band for private 5G deployment might represent a potential barrier to achieving economies of scale for private 5G deployment. Globally, there are also varying approaches on private 5G deployment, meaning that a large industrial company operating either in multiple European markets or globally might face challenges to procure a 5G private network solution compatible with the spectrum and technological conditions applicable to each of its markets. The issues of device availability, cost and demand prioritisation by suppliers may propagate into the UK 5G market as scale is achieved in other leading regions.

Demand-side barriers

Concerns over business case/value is a key demand-side barrier for individuals and businesses

As with the supply-side, concerns over the business case for investing in 5G is a barrier on the demand-side. This demonstrates the 'chicken and egg' problem described above under the supply-side barriers heading – both the supply-side and the demand-side need each other to demonstrate the business case for 5G adoption. Individual and business willingness to pay for 5G services could represent a key barrier affecting 5G demand across all consumer groups. Other barriers related to the business case/value of 5G investment might include: lack of business case/understanding of ROI; concern over upfront capital costs; and lack of visibility of total cost of ownership (TCO) / concern over ongoing/monthly costs.

An underdeveloped 5G ecosystem and complexity with integration with legacy technologies hinder the feasibility of 5G adoption

On the demand-side, the feasibility of 5G adoption depends on, amongst other factors, the readiness of the ecosystem. Over and above network supply, demand would need to be supported by an entire 5G ecosystem of embedded devices, software, chipsets and modems. Due to the current lack of scale of demand, consumers implementing 5G technology may be faced with a high cost of equipment, exacerbated by the need for more tailored devices and solutions to meet their standards and spectrum requirements, escalating costs and extending lead time to device production. Another feasibility barrier to adoption is the complexity of integrating new 5G solutions with existing technology and systems. It is noted that the difficulties here lie with implementation of a bridge supporting legacy technologies rather than with the new technologies themselves.

Security concerns also hinder the feasibility of 5G adoption

As cited in several studies, security and data privacy concerns might represent a barrier to 5G adoption by some consumer groups, and may also hold back the feasibility of users adopting 5G whilst security and/or data privacy issues are resolved, compatible with different industrial security requirements. Multiple surveys we reviewed found concerns around data security to be a major barrier to 5G demand (Digital Catapult 2019; Ericsson 2018; Infosys 2019; GSMA 2020b, Nokia 2020), with moving data to the cloud a particular concern. Some users prefer that the data which is generated on their site does not leave their site, hence the ability to have local processing on their site is very important.

Many users do not view 5G as critical for their needs

Another type of barrier relates to the extent to which potential adopters of 5G view the technology as critical for meeting their future needs (or whether existing solutions might be sufficient). Some studies we reviewed pointed to a lack of evidence of 5G's suitability as holding back demand. This was supported by responses from stakeholders, which indicated a reluctance by some potential users to adopt 5G until they had seen it demonstrated and proven elsewhere; or that they were not convinced that 5G was essential for their needs. This points to a need for a diverse range of use cases to be showcased over 5G infrastructure in order to demonstrate the benefits in specific environments. Similarly, a lack of technical understanding of 5G might prevent some users from implementing solutions. This lack of evidence and understanding of 5G's applications and implementation requirements may be the reason many consumers see existing technologies (e.g. fibre/4G/Wi-Fi) as sufficient to meet their needs.

Testbeds and trials play an important role in demonstrating the value of 5G to users

Access to the 5G Testbeds and Trials (5GTT) programme is expected to be of significant importance to larger and smaller businesses, and public sector users, looking to understand the full capabilities benefits of 5G to meet their specific needs and environment. Testbeds and trials are generally less relevant for validating individual consumer use of 5G (i.e. mobile broadband), since this use case exists in the UK 5G networks already. This might be one reason why MNOs have not been active partners in initial 5G Testbed and Trials projects, although it is noted that MNOs are now increasingly involved. There appears to be demand from businesses for increased diffusion of findings from relevant 5G trials and testbed projects so that users not involved in the projects can still benefit from the findings. As such, inviting industry players to witness the benefits of relevant 5G projects within the testbeds and trials programme may be useful, along with publicising the outcomes.

The outcomes of UK 5G test bed and trials need to be expressed more clearly

For progression of the 5GTT in the UK, it would be helpful if outcomes of the programme are published including details of solutions used, breakdown on upfront costs, and benefits delivered by the trial or use case (e.g. improvement in ROI, productivity, etc.). As the 5G market evolves it is anticipated the 5GTT projects should go beyond the proof of concept (PoC) stage, towards demonstrating benefits in real world environments. An increased focus on key sectors might also be beneficial.

5.4 Relevance of demand-side barriers within different consumer groups in the UK

Based on our analysis we consider that demand-side barriers can be split into two types:

- '**macro barriers'**: cross-market barriers that cut across multiple areas / consumer groups and 5G applications across most of the 5G market. The most relevant macro barriers identified through the study are:
    - willingness of individuals and businesses to pay for 5G services
    - lack of evidence of 5G's suitability for the specific use case connectivity requirements, together with uncertainty over timing of investment into full functionality 5G needed to enable specific use cases and features to be adopted at scale across the UK
- '**micro barriers'**: micro barriers apply more to some consumer groups / 5G applications than others, but can be grouped into distinct general categories, e.g. device availability.

- o Barriers specific to different consumer groups are outlined in Table 5.1, which presents our view of what micro demand-side barriers are likely to affect each consumer group
- o these consumer-group specific barriers may affect the timing and/or rate of adoption for the sectors within that consumer group.

It is noted that we have assessed barriers at the consumer group level, which ignores that in practice, individual sectors within consumer groups might take up 5G solutions at difference paces. In this study we found there to be insufficient evidence to define the impact of barriers at the sector-specific level.

The key micro barriers affecting most consumer groups were found to be a lack of understanding of 5G and the benefits of using 5G, the ecosystem not being ready / fully available and lack of business case / understanding of ROI (outlined in red in Table 5.1). The output of our analysis is shown below. It should be noted there is significant uncertainty surrounding the key areas of concern over 5G adoption within different consumer groups, and sectors within those consumer groups. Hence the table below represents our best view on the key barriers that might exist per consumer group, at the time of producing this report.

Table 5-1: Micro barriers per consumer group

	1	2	3	4	5	6	7	8	9
	Media and Entertainment	Public services	Energy and Utilities	Rural industries	Smart urban	Transport	Manufacturing logistics and distribution	High-speed broadband into homes and offices	Retail and Hospitality
Lack of understanding of 5G and the benefits using 5G offers		■	■	■	■	■	■		■
Existing technologies (e.g. fibre/4G/Wi-Fi) are seen as sufficient	■	■	■			■		■	■
Ecosystem not ready / fully available	■	■	■	■	■	■	■		■
Complexities of integrating with existing technology and systems		■				■			
Cultural resistance to change		■		■		■			■
Security concerns / moving data to the cloud		■			■	■	■		■

Lack of business case / understanding of return on investment (ROI)									
Concern over upfront (capital) costs									
Lack of understanding of total cost of ownership (TCO) / concern over ongoing costs/monthly data costs									

Source: Analysys Mason, Literature review.

Further supporting evidence on the supply-side and demand-side barriers described above and how these might impact 5G adoption in the UK, based on the evidence captured in this study, is summarised below.

5.5 Supply-side barriers – supporting evidence

Radio deployment technical and regulatory issues

In a report for the broadband stakeholder group, Analysys Mason (2018) identified planning regulations as a specific legislation barrier:

- “There is a lack of consistency in how local authorities apply planning rules and regulations vary across the devolved nations. […] The uncertainty this creates is hampering operators from gaining access to new sites and upgrading existing ones.”
- “Fragmented application of planning regulations for mobile equipment, and a lack of best-practice guidance, introduces additional costs for both local authorities and network providers and is limiting the ability of network providers to plan an efficient deployment of 5G.”

Previous published surveys also indicate several supply-side challenges. For example, 441% of respondents identified ‘entirely new 5G radio deployment’ as a deployment challenge, 32% of respondents identified ‘integration with existing network and systems’, and 52% identified ‘government regulations’ as an adoption barrier to 5G (this was the second most common barrier identified) (Infosys 2019).

The European Commission published a recommendation in 2020 about “a common Union toolbox” for 5G. It highlighted issues with regulatory procedures and stated that “Member states should […] make improvements in the following areas (i) streamlining permit granting procedures […] (ii) increasing transparency […] (iii) expanding the right to access existing physical infrastructure controlled by public sector bodies and (iv) improving the dispute resolution mechanism” (European Commision 2020b)**.**

“The introduction of 5G presents incumbent operators with new business opportunities and new business models. It also constrains current forms of competition, while opening up new ones. Hence, regulators and competition authorities will need to appreciate the new rules of the game and will have to be vigilant to assure competition is promoted and investment stimulated. This applies at the Member State level, as well as the EU level” (Cerre 2019)**.**

In 2019 OECD published a report on “The Road to 5G Networks”. This highlighted that “new regulatory issues arise with 5G, and one main concern for stakeholders relates to power density regulation (or electromagnetic limits in a given location)”. The report stated that “key regulatory issues will include: streamlining rights of way (to deploy massive numbers of small cells and backhaul connecting the cells), efficient spectrum management, deployment and access to backhaul and backbone facilities, and new forms of infrastructure sharing. … 5G will make new demands on all stakeholders in areas such as rights of way, particularly in terms of the location and backhaul to support smaller cells (OECD 2019).

Integrating with existing network and systems

43% of respondents identified ‘integration with existing network and systems’ as a deployment challenge (Infosys 2019). 38% of supply (telecoms and media) respondents said that ‘integrating with existing network and systems’ was a deployment challenge (Infosys 2019).

Migration to virtualised stand-alone 5G core networks

38% of respondents identified ‘virtualised 5G core deployment’ as a deployment challenge (Analysys Mason 2018).

“The current biggest barrier to roll-out is undoubtedly economic, with the business case being balanced against the risks of investing […] more infrastructure needs to be deployed (antennae, base stations and small cells – as well as the fibre-optic cables to connect these). This all costs significant levels of capital… the overarching barrier to the UK being a 5G leader is one of investment uncertainty” (Analysys Mason 2018).

“5G will accommodate a large variety of scenarios in terms of usage; therefore, the network architecture will have to be flexible to meet this demand. One way to introduce this flexibility is through network slicing in order to improve efficiency” (OECD 2019).

Geographic coverage is required for some use cases

“The biggest barrier to adoption is coverage, with 54% of those who are not currently planning for it saying they’re waiting for 5G to be available in more places. It’s a particular barrier for larger, multisite and multinational businesses, which would prefer to be able to implement 5G services everywhere rather than have some locations running ahead of others” (Nokia 2020)

Even in areas where 5G is available, 10% of consumers cite “coverage area too limited” as a barrier to use (Nokia 2020b). 18% of UK enterprises pointed to lack of coverage as a stumbling block Nokia 2020c).

Access to and availability of backhaul

“An increase in network densification raises the question of having sufficient backhaul capable of meeting the requirements of 5G […] access to backhaul and investment in NGA networks [is a] key enabler of 5G […] [small] cells will need to be connected to backhaul, underlining the need for increased investment in next generation network deployment” (OECD 2019).

5G commercialisation prioritises B2C initially / proven use cases

(Deloitte China 2018b) highlighted that “centred round industry application scenarios, 5G network deployment will be driven by applications. In the short and medium term, 5G will be implemented firstly in the application scenarios of enhancing mobile broadband”. Elaborating that “due to high investment and incomplete standards in relation to 5G deployment, it is expected that telecom operators will adopt longer-term and more flexible deployment based on the needs of application scenarios. Application scenarios of enhancing mobile broadband will be implemented firstly in regions of high user density. Correspondingly, downstream application scenarios with mature technology and high economic value would be given priority in the implementation of 5G network. More technical barriers will be broken down over time, and economic value brought by 5G-based downstream applications will be increasingly emerging in more scenarios”.

A Mobilise Global (2019, Mobilise Global 2019) whitepaper states “it is becoming clear that enterprises are not convinced that telecom operators can meet their needs, and as a result, are building out their own private networks”, explaining that “in the 5G era, that operator platforms will need to support massive IoT, network slices using virtualised network functions, and common enablers and APIs. To fully address these business-oriented opportunities, operators will need to focus on business-to-business (B2B) and business-to-business-to-consumer (B2B2C) business models”. The same paper also cited “a recent GSMA paper” where “they put forward the argument that “enhanced mobile broadband (eMBB) will be the key proposition in early 5G deployments and will drive increased performance, functionality and efficiency across society. This is the clearest, potential 5G use case and will support the delivery of high definition video (e.g. TV and gaming), immersive communication (e.g. video calling and augmented & virtual reality) and smart city services (e.g. video cameras for surveillance).””

Features available in 3GPP releases not fully implemented in vendor/operator networks

“The standard setting process is [not] completed. In fact, the industry is now working on Release 16, where new 5G technologies will expand the ecosystem. Commercial launches from 2021-22 are expected to be based on Release 16, which will focus on IoT usage scenarios (i.e. massive machine type communications and ultra-reliable low-latency communications). More specifically, Release 16 of the standard, expected to be finalised in June 2019, is focusing on a variety of topics, such as Vehicle-to-everything (V2X) applications, 5G satellite access, Local Area Network support in 5G, wireless and wireline convergence for 5G, network slicing and the IoT, among others” (OECD 2019).

76% of Ericsson (2018) respondents identified ‘lack of standards’ as a key barrier to 5G adoption in 2017 – the second most common barrier that year.

“There is some ambiguity in the term 5G, which may be part of the reason why businesses are holding off on investment. In fact there are no internationally agreed specifications or definition for a 5G network yet” (Barclays 2019).

Barriers within the value chain

In 2016 Cisco published a white paper looking into the "vertical value creation of 5G". It found that "with operator value continuing to shift away from basic connectivity services, the 5G mobile architecture needs to enable operators to use their networking assets to quickly and efficiently support new value-added services". Explaining that "conventional cellular networks have looked to interface with third parties, exposing a limited set of core network capabilities and often using proprietary interfaces. But 5G requirements include the ability to accelerate integration of 5G connectivity services into a wide range of vertical systems" (CISCO 2016).

A Deloitte (Deloitte 2018b) report states "in the age of 5G, the role of telecom operators would be extended from providing 5G infrastructure and connection services to participating in the development of 5G-enabled downstream application scenarios and driving 5G investment with the maturity of downstream applications, thereby building a closed business loop". The report identifies "co-development of vertical industry platforms: e.g. co-development of platforms related to IoV, smart healthcare and smart factories, etc. with other partners in the ecosystem" as part of the "evolution of the business model of telecom operators".

(Mobilise Global 2019) said "we expect the initial target segments will be the consumer market and 'horizontal' enterprise services (e.g. laptop connectivity). Whilst there is the potential to offer new services to industrial verticals - such as autonomous vehicles for the automotive sector, this is some way in the future and in fact might never materialise due to the significant infrastructure investment required. However we may see new innovations such as UAV (unmanned aerial vehicles, drones), developing into a potential new segment/ application category."

Cost of spectrum/ annual licence fees

"While 5G, like 4G, is not proving to be the cash bonanza that was 3G, the sums already spent are high. The spend created at auctions per MHz/pop is improbably uneven relative to likely demand or requirements; it is to a large extent a function of the way the auctions are set up. So for example there is insufficient difference on the demand side to explain why 3.5GHz spectrum in Italy commanded a value some seven times higher than in Finland." (ETNO 2021).

"Member States should be encouraged to identify spectrum authorisation rules that aim to apply a pro-investment spectrum pricing methodology […] avoid spectrum scarcity that leads to higher bids in spectrum auctions" (European Commision 2020b).

Lack of availability of full 5G spectrum portfolio

Lack of availability of the full 5G spectrum portfolio (i.e. 700MHz, 3.6GHz and 26GHz spectrum bands) might be a supply-side barrier in markets where these bands have not been made available. However, as of March 2021 (after receiving stakeholder input) Ofcom awarded available 700MHz and 3.6-3.8GHz spectrum to UK MNOs. Additionally, if the 26GHz band becomes available in the next 12 months for mobile use in outdoor environments (e.g. by MNOs), we would expect the relevance and significance of this supply barrier to be low. There are some 5G use cases that rely on reliable uplink capacity (e.g. immersive media experiences, industrial use cases such as remote piloting of equipment),. This uplink capacity requirement might vary at a local level, which is currently difficult to deploy using nationally planned eMBB networks since variations in uplink and downlink dimensioning would give rise to additional interference issues. Spectrum such as the 26GHz band might provide the MNOs with additional options to provision capacity in different ways at a localised level.

“Roll-out of 5G in Europe has been patchy, and 5G still represents a low single-digit percentage of total connections in all countries. One factor that holds back the market is slow and patchy releases of spectrum, which often creates an artificially high cost of spectrum” (ETNO 2021).

Analysys Mason (2018) identified access to spectrum as a specific legislation barrier: “Insufficient spectrum and barriers to accessing spectrum, particularly for local providers and for indoor systems may inhibit wider deployment of 5G”

“The European Electronic Communications Code sets a common deadline of the end of 2020 for the Member States to allow use of the 3.4-3.8 GHz band and at least 1GHz of the 24.25-27.5GHz pioneer frequency band for 5G. In addition, Decision (EU) 2017/8999 sets a common deadline of 30 June 2020 for the Member States to allow use of the 700 MHz pioneer frequency band for 5G. […] Member States should avoid or minimise any delays in allowing use of 5G pioneer frequency bands due to the COVID-19 crisis” (European Commision 2020b).

“Spectrum is the primary essential input for wireless communications, and therefore, its timely availability is of critical importance for 5G” (OECD 2019).

5.6 Demand-side barriers – supporting evidence

Macro barriers – supporting evidence

Lack of evidence of 5G’s suitability / use cases

The evidence we have captured supporting a need for additional guidance to be available on 5G use (i.e. ‘lack of evidence of 5G’s suitability’ as a barrier) is as follows.

In 2019 Digital Catapult interviewed more than 40 UK manufacturing executives, moderated three round-table discussions and carried out an industry survey. Survey respondents’ companies were located all across the UK (ranging from 5% in Wales to 20% in London) and varied in size from 1-50 employees (38% of respondents) to more than 2500 employees (31% of respondents). The study found that “5G is nascent, however, making examples of proven ROI in deployments scarce” (Digital Catapult 2019).

During 2016 and 2017, (Ericsson 2018) conducted a survey of companies with at least 1000 employees across ten industries[22] worldwide, interviewing approximately 100 executives per industry. The fourth most common key barrier in Ericsson’s 2017 survey was ‘too soon to know what the real benefits will be’ which was selected as a key barrier to adoption of 5G by 62% of respondents, up from 50% in 2016. Additionally, in 2016, 51% of respondents identified ‘lack of applications’ and 56% identified ‘lack of use cases’ as key

[22] Automotive, retail, media and entertainment, manufacturing, energy and utilities, agriculture, public transport, financial services, healthcare and public safety.

barriers to 5G adoption. By 2017 those numbers had dropped slightly to 41% and 47% respectively.

(Infosys 2019) conducted a research survey in 2019 of 850 industry leaders from firms with more than USD1 billion revenues across six broad industry categories[23]. The respondents were primarily US-based (49%) but 13% respondents were UK-based. 42% of respondents chose 'no compelling use case' as an adoption barrier to 5G.

(Nokia 2020) surveyed 1000 IT decision-makers in the US and the UK from small, medium and large organisations across seven sectors[24]. They found that "decision-makers become enthused about 5G when they see specific contexts in which it can be used, suggesting that concrete examples and case studies will help to speed adoption."

Willingness to pay

GigaTag's Interim Report (GigaTAG 2020)found that "consumers may be unwilling to pay much more than they do now for a gigabit-capable connection. This may be because there is not currently a significant benefit to them, or due to price sensitivity".

(Which? 2020) found that "only 18% of broadband decision-makers would be willing to pay more than they do now to have gigabit-capable broadband". Although (Nokia 2020b) found that "50% are willing to pay more for 5G".

Micro barriers - supporting evidence

Lack of understanding of 5G and the benefits using 5G offers

A Barclays study (Barclays 2019) surveyed 526 medium-sized and large businesses from a wide range of sectors[25]. Across British businesses, Barclays found that "there's a lack of understanding of what 5G can do for industry - only 28% of businesses know what 5G is and what it could do on a practical level". "14% of British firms are not even aware of 5G" and "more than half [of the managers that know what 5G is] were unsure about how it would work practically", and "only 9% of managers plan to invest significantly in enabling 5G operations over the next 5 years"**.** Furthermore "most British firms don't know that 5G will arrive in the next 12 to 18 months". The report went on to highlight that "this blind spot is not just concentrated in certain regions, as might be expected", but was prevalent throughout the UK.

Digital Catapult's (2019) study identified "current lack of understanding of how 5G differs from other connectivity solutions" as another key challenge. More than 30% of survey respondents listed 'lack of skilled staff' as one of the

[23] Consumer goods, retail and logistics (20%); communication, media and technology (15%); energy and utilities (9%); financial services and insurance (12%); healthcare, life sciences, government and agriculture (18%); and industrial manufacturing, automotive and high tech (26%).

[24] Energy, retail, manufacturing, government and public safety, automotive and transportation, media and advertising, and education.

[25] The respondents came from the manufacturing, retail, technology, media and telecoms, business services, healthcare, educations, hospitality and leisure, logistics and charitable sectors.

biggest barriers to deployment of 5G technology for their organisation and more than 40% chose ‘not knowing where to start, who to speak to’. Additionally only one third of manufacturing companies say they have “good knowledge of 5G”.

Cerre’s whitepaper on ambitions for Europe (Cerre 2019) in the 2019-2024 period stated that “it appears that the transition from 4G to 5G lacks the stepwise improvement that has led to the success of 2G-GSM”**.**

49% of (Infosys 2019) respondents cited ‘understanding of the technology’ as an adoption barrier for 5G. Lack of understanding and relevant skills relating to 5G requires training and reskilling of the workforce, and 51% of respondents selected ‘Training and hiring’ as an adoption barrier to 5G.

As IoT is a complementary tool to 5G emergence, barriers to IoT adoption may cascade to 5G as well. As such we reviewed an IoT enterprise survey conducted by GSMA Intelligence in 2018, 2019 and 2020 to collect insights from more than 2000 enterprises with at least 20 employees representing eight vertical sectors[26] and 18 countries[27]. (GSMAi 2020b) found that 38% of enterprises felt ‘a lack of in-house skills’ was a challenge for IoT deployment.

(GigaTAG 2020) identified ‘lack of awareness’ as a barrier to consumer adoption of gigabit-capable broadband, stating that consumers were ‘unclear how it differs to other connections (on the market and their own)’. They also identified that “Understanding: of ‘gigabit-capable broadband’ is low amongst businesses across the UK”, with CBI data showing that 14% of respondent businesses “didn’t know what gigabit connectivity is”, with 36% of firms indicating that “not knowing when gigabit-capable connectivity would be available in their area was a barrier to adoption”. Additionally, “the GigaTAG’s research so far indicates that businesses also face a range of skills barriers that hinder adoption: of firms that hadn’t already adopted gigabit capable connectivity, almost one in ten (9%) business respondents in the CBI’s survey said they did not have the skills needed to adopt gigabit-capable technologies effectively”.

Analysys Mason (2018) interviewed 23 stakeholders and received comments from government departments. They identified one overarching issue for 5G deployment: the need to clearly articulate the value that 5G roll-out in the UK will bring. “Both industry stakeholders and local authorities raised overarching concerns that:

- There is a need for greater clarity and wider promotion of the value of 5G roll-out, and clearer definition of the UK’s 5G strategy, to reduce uncertainty for industry
- There is a lack of awareness of nationwide 5G priorities within local authorities, which risks delaying 5G roll-out if not addressed in the short term”

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[26] Retail, utilities, transportation, healthcare, public sector, manufacturing, automotive and consumer electronics.

[27] Argentina, Australia, Brazil, China, France, Germany, India, Indonesia, Japan, Mexico, Russia, South Africa, South Korea, Spain, Sweden, Turkey, UK and USA.

Of those surveyed by (Nokia 2020), a large minority (30%) said "they need more information about what 5G can do for their organisation before starting to plan". This lack of information was the second biggest barrier to adoption identified after lack of 5G coverage.

A Nokia study (Nokia 2020b) of more than 3000 adults aged 18 and older who are smartphone owners, broadband internet users, and the primary decision makers in their household in the USA, the UK and South Korea (1000 from each[28]) found that although 80% of consumers familiar with 5G find it appealing, only 23% of those unfamiliar with 5G find it appealing – showing the impact of lack of understanding of 5G on likely adoption. The corresponding (Nokia 2020c) enterprise survey which surveyed 1628 technology purchasing decision makers in eight markets[29] and across six industry sectors[30] found that "companies may appreciate the benefits of 5G in theory, but not all understand how they would actually use it within their organisation", with 14% of UK respondents saying "a key barrier is that decision-makers within the business do not understand 5G", 12% saying "they don't know enough about it themselves" and 9% saying "I don't understand the true benefits". This was reinforced by the 36% of global respondents who said that "a better understanding of 5G, and the benefits it offers, would encourage them to invest more".

Existing technologies (e.g. fibre/4G/Wi-Fi) are seen as sufficient

Roughly 25% of (Digital Catapult 2019) survey respondents listed 'existing network solutions cover my needs' as one of the biggest barriers to deployment of 5G technology for their organisation. Digital Catapult also found that "manufacturers often incorrectly believe that their existing connectivity capability already performs around 80% of what 5G is expected to deliver"**.**

(Barclays 2019) concluded that "a slower rate of network development and a less vigorous customer response to the availability and services […] could be because […] a higher proportion of customers remain happy with the service they get from 4G and are slower to switch over."

60% of respondents in 2016 listed 'opportunities related to current generation of mobile networks not yet fully exploited' although that had dropped to 44% by 2017 (Ericsson 2018).

A report by Analysys Mason into spend on LTE/5G private networks suggests that the cost of deploying private LTE/5G private networks is high compared to alternatives such as Wi-Fi. Thus, there is a risk that only relatively large enterprises can afford to deploy them. Small and medium sized enterprises (SMEs) and some other industrial users might therefore be excluded due to cost concerns, as well as complexity. The same Analysys Mason report also found "brownfield sites with a complex technology environment make integration challenging: most industrial environments are brownfield sites; they already have a plethora of networking technologies in place. Installing new, additional technologies can be complex and costly".

[28] Demographic quotas were set for age, gender, and household income to ensure samples were representative of the population of each market surveyed.

[29] Australia, Finland, Germany, Japan, Saudi Arabia, South Korea, UK, and USA.

[30] Energy and utilities, mining, manufacturing, public sector, healthcare, and transportation.

GigaTag's Interim Report (GigaTAG 2020) found that "the services people have, or have available to them (i.e. superfast broadband), currently meet the needs of the majority" they cited (Which? 2020) research that found that "73% of broadband decision-makers said that their connection met their needs during lockdown" and Ofcom (Ofcom 2020) research which found that "the majority (82%) of people are satisfied with the speed of their service".

28% of people surveyed by (Nokia 2020) say they " want to make the most of their existing network equipment before upgrading".

(Nokia 2020b) found that in areas where 5G is available 44% of consumers identified "4G service is good enough for me" as a barrier to use.

Ecosystem not ready/ fully available

(Barclays 2019), although optimistic about "early adopters", highlighted that "it's the killer apps and the incredible new devices that bring everyone else on board", stating that the networks are nothing without devices and applications to run on them" although they did see "evidence of ample investment [in these]". In their model they stated that if "killer apps that encourage fast take-up are slower to emerge" then there could be "a slower rate of network development and a less vigorous customer response to the availability and services".

(Digital Catapult 2019) found that as part of interviewees concerns regarding compatibility and interoperability with existing solutions, they had uncertainties regarding "any other system solutions sitting on top of a network".

(Ericsson 2018) found that in 2016, 53% of respondents chose 'lack of a mature ecosystem' to be a key barrier to adoption of 5G. This had decreased to 45% by 2017, although a second category, 'lack of platforms to take full advantage of 5G' was also added in 2017 and 46% of respondents identified that as a key barrier.

(Infosys 2019) found that 49% of respondents selected 'device readiness' as a barrier to 5G adoption, and 51% selected 'lack of technology maturity'. The latter was identified as being especially relevant for UK respondents.

45% of (Nokia 2020b) respondents selected "do not own a 5G phone" as a barrier to use in areas where 5G is available. The corresponding enterprise survey identified one barrier as "Ecosystem availability - 5G currently exists in pockets of availability. Some urban cities have 5G networks and a minority of organisations have developed private 5G networks – but it is not yet the network standard. As such, the most-cited barrier to 5G investment and implementation was 'availability of 5G-enabled products', mentioned by 29% of UK decision-makers" Nokia 2020c).

Complexities of integrating new 5G solutions with existing technology and systems

(Digital Catapult 2019) found that "Interviewees were concerned about compatibility and interoperability with existing solutions" and hence identified "Concerns around compatibility and interoperability of mobile networks when it comes to integration into existing industrial systems" as one of five key challenges facing 5G adoption within manufacturing.

In 2017 'challenges of end-to-end implementation' was added to the (Ericsson 2018) survey, and 69% of respondents selected it as a key barrier, making it the third most common key barrier to 5G adoption.

(GigaTAG 2020) identified ‘hassle related to the switch – requirement for engineer visits [for gigabit capable connection installation]’ as a barrier to consumer adoption of gigabit-capable broadband.

(Which? 2020) found that “22% of broadband decision-makers didn’t want someone to come to their home to install a new connection”.

In 2020, ‘integrating with existing technology’ was the most common challenge to IoT deployment identified in GSMAi’s survey (GSMAi 2020b) having been selected by 53% of enterprises. It was also one of the top three challenges identified in the two years prior.

43% of (Infosys 2019) respondents identified ‘integration with existing network and systems’ as a challenge to deployment.

Cultural resistance to change

“Cultural barriers to working with companies in different sectors such as telecommunications, as well as start-ups” was identified as one of five key challenges in manufacturing in Digital Catapult’s study (Digital Catapult 2019).

(Ericsson 2018) found that in 2016 49% of respondents felt that ‘senior stakeholder buy-in/concerns’ was a key barrier to 5G adoption. By 2017 that number had increased to 54%.

In 2020, 40% of enterprises identified ‘employee/internal resistance’ as a challenge to IoT deployment (GSMAi 2020b).

Security concerns / moving data to the cloud

Another one of Digital Catapult’s five key challenges for manufacturing was the “need for security” stating that “manufacturers want control over the security of their connectivity and data, as well as the connectivity itself, to assess the quality of service. They have concerns about connecting production lines to external stakeholders without expertise in their sector”. Particular challenges include “no clear ownership of risk, limited control or visibility of future changes, potential for giving part of their capabilities away to a third party, and concerns over long term service level agreements (SLAs)”. This was further evidence by c.30% of survey respondents listing ‘concerns over security’ as one of the biggest barriers to deployment of 5G technology for their organisation (Digital Catapult 2019).

In 2017, the most common key barrier (Ericsson 2018) identified was ‘concerns around data security and privacy’ which was selected by 79% of respondents, up from 60% in 2016.

‘Data security’ was the most commonly cited barrier in Infosys’ survey (Infosys 2019) with 59% of respondents identifying it as an adoption barrier to 5G, this was consistent across regions.

‘Security and data privacy concerns’ was identified by enterprises as one of the top three challenges to IoT deployment in 2018, 2019 and 2020, with 50% of enterprises selecting it in 2020 (GSMAi 2020b).

34% of enterprise respondents in (Nokia 2020c) were “concerned about the security of 5G” rising to 40% in healthcare and 43% in the mining industry. In turn, 22% cited security risks related to 5G as a primary barrier to its implementation.

Lack of business case / understanding of ROI

Digital Catapult's study also identified "lack of demonstrable cost-efficiency and return on investment" as one of five key challenges, stating that "a clear ROI and business case is crucial to the introduction of 5G in manufacturing, according to our interviews". More than 70% of survey respondents listed 'lack of understanding of ROI and value' as one of the biggest barriers to deployment of 5G technology for their organisation, agreeing with this finding (Digital Catapult 2019).

(Barclays 2019) found that "nearly half of companies reported that they didn't expect to see an increase in business revenues from the advent of 5G", and in particular "only 7% of managers in the Healthcare industry are expecting a significant increase in revenue compared to the highest reported figure of 26% of Logistics businesses."

(Cerre 2019) highlighted a need to reduce market uncertainty in order to stimulate investment.

(GigaTAG 2020) found that "a number of businesses perceive there to be little current benefit in taking up gigabit capable technologies – with a third of respondents to the CBI Tech Tracker Survey stating that they have no current plans to invest in gigabit-capable technologies". The report also states that "of businesses that had not already adopted gigabit-capable technologies, almost one-in-five (19%) didn't see the Return on Investment of gigabit-capable technologies."

In 2020 27% of respondents identified 'unclear ROI' as a challenge to IoT deployment (GSMAi 2020b).

(Nokia 2020) stated that "demonstrating ROI will be key to success".

Concern over upfront (capital) costs

The percentage of respondents in (Ericsson 2018) who identified 'lack of budget/investment' as a key barrier to 5G adoption increased from 60% in 2016 to 61% in 2017.

'Cost of implementation' has been identified as one of the top three challenges for IoT deployment among enterprises for 2018, 2019 and 2020, with 47% of respondents selecting it in 2020 (GSMAi 2020b).

50% of (Infosys 2019) survey respondents indicated 'investment involved' was an adoption barrier to 5G.

30% of consumers in areas where 5G is available cite "5G phones are too expensive" as a barrier to use (Nokia 2020b).

In the UK 17% of enterprises cited "the costs are too high" as a barrier to 5G investment (Nokia 2020c).

Lack of understanding of total cost of ownership (TCO) / concern over ongoing costs/ monthly data costs

Nearly 60% of Digital Catapult's survey respondents listed cost as one of the biggest barriers to deployment of 5G technology for their organisation (Digital Catapult 2019).

38% of consumers in areas where 5G is available said that "5G data plans are too expensive" (Nokia 2020b).

6 Modelling the adoption and benefits of 5G

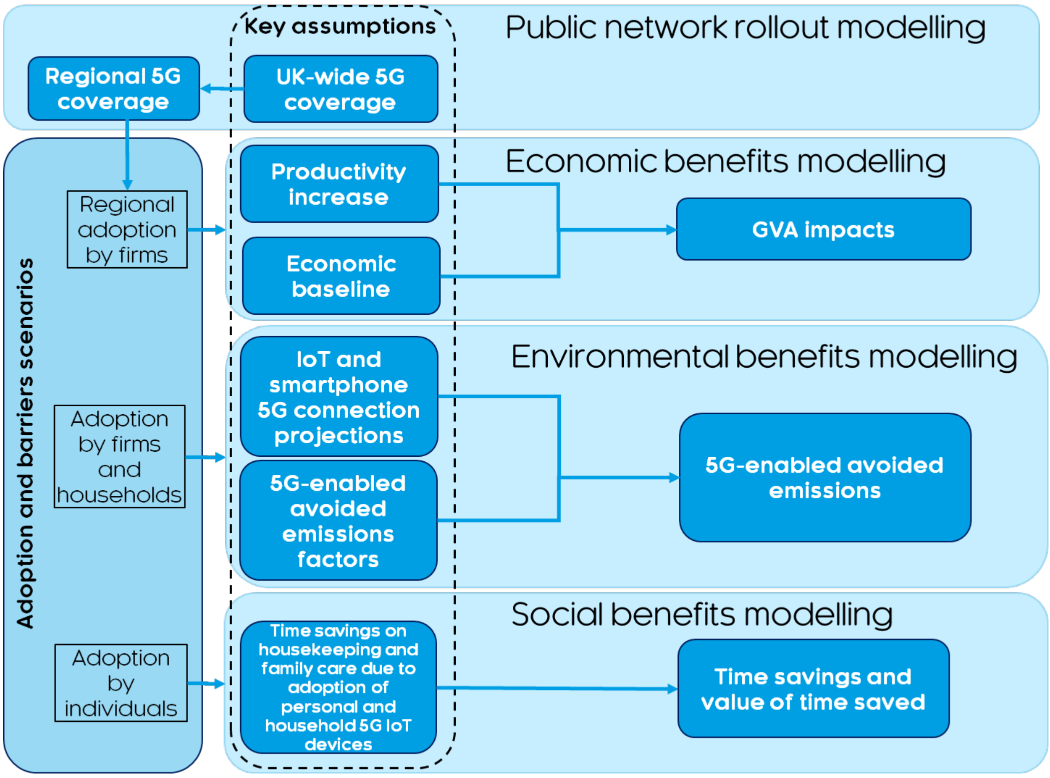
6.1 Overview

This section describes our approach to modelling 5G adoption in the UK and estimating the economic, environmental, and social benefits. The modelling can be broken down into three components:

- Modelling UK-wide adoption and market barriers and modelling of public network roll-out
- Disaggregating UK-wide adoption projections for the UK regions, Scotland, Wales and Northern Ireland, and also for rural and urban areas of each region and country
- Estimating economic, environmental, and social benefits

A diagram showing simplified linkages between these components is presented in Figure 6-1. It shows how outputs of these components are used as inputs by other components. The diagram also shows the key assumptions underpinning each stage of modelling.

Figure 6-1 Model logic diagram



Source: Cambridge Econometrics and Analysys Mason.

6.2 Adoption and barriers model

We have considered the adoption of 5G applications, modelled as the take-up of each group of use cases by each consumer group, over a 15-year period (2020–35). The resulting adoption curves are expressed as a percentage of the addressable market. This section outlines the approach taken to model adoption curves, taking into account associated barriers for 5G applications.

Using 5G enablement curves to quantify demand for 5G

Published data on '5G enablement' from GSMA was used as a starting point in developing these adoption curves. 5G enablement represents the progressive impact of 5G on the economy, over a 15-year timescale (i.e. 2020–35), by consumer group and types of 5G application. The GSMA modelled these benefits as starting from 2020 and achieving 100% realisation by 2035. With this information as a starting point, taking into account the evidence base analysed in this study along with Analysys Mason's own insight and experience, we refined these into a UK-specific set of 5G enablement curves, mapped to our consumer groups and 5G applications definitions.

The GSMA report (GSMA 2018) provides unweighted forecasts for 5G adoption or enablement, by 5G feature, for a number of country categories. The GSMA's curves were derived based on industry research, 4G adoption, and inputs from a panel of experts. The experts were asked their views on how quickly different 5G use cases might be adopted, in different world regions. Key threshold years (the year the 5G use case will be initially deployed, and the year the use case will reach maturity) were defined for different types of market (advanced adopters, early adopters, late adopters). Whilst the UK was not specifically modelled, we envisage it would fall into the 'early adopter Europe' category defined by the GSMA.

The figures below show a selection of the GSMA's forecasts and underlying enablement assumptions.

Table 6-1.: Example of 5G enablement assumptions – Early Adopters Europe (retained for the UK)

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
High-speed Broadband in the Home	0%	0%	1%	1%	3%	6%	11%	19%	31%	45%	60%
High-speed Broadband in the Office	0%	1%	2%	3%	5%	9%	15%	23%	35%	48%	61%
Ultra-Low Cost Networks in Rural Areas	0%	0%	0%	0%	1%	2%	3%	6%	11%	18%	29%
Dynamic Hot Spots	0%	1%	2%	3%	5%	9%	15%	23%	35%	48%	61%

Note: 0% in this table represents negligible/no adoption of the respective 5G use case.
Source: Analysys Mason.

Translating barrier impact into enablement scenarios

We model demand-side barriers as having an impact on both the timing (i.e. a delay in adoption starting) and rate of adoption (i.e. a slower adoption over time)[31]. We have assessed for each consumer group how barriers for specific 5G applications will impact adoption. A summary of our findings for the AR/VR 5G application in the Public services consumer group is presented in the table below:

Table 6-2.: Barrier assessment overall rating – AR/VR illustration

Barriers to adoption	Delay to adoption	Impact on rate of adoption	Relevance of barrier
Existing technologies (e.g. fibre/4G/Wi-Fi) seen as sufficient	3	4	6%
Lack of business case / understanding of ROI	4	3	17%
Concern over upfront (capital) costs	*0*	*0*	*0%*
Lack of understanding of total cost of ownership (TCO) / concern over ongoing costs/monthly data costs	2	2	6%
Cultural resistance to change	2	2	6%
Ecosystem not ready / fully available	3	4	17%
Security concerns / moving data to the cloud	3	3	17%
Lack of understanding of 5G and the benefits using 5G offers	3	4	28%
Complexities of integrating with existing technology and systems	1	2	6%
Overall rating	4	3	100%
	= MAX [Delay to adoption]	= Weighted Ave [Rate of adoption x Relevance]	
Overall scenario	Mid-term: 4 years delay	Slow adoption rate	

Note: Delay to adoption is the number of years (from 2021) the start of adoption is delayed by. Impact on rate of adoption sets the curve of adoption to one of four options (limited early adoption, slow adoption, medium adoption, rapid adoption. Relevance is a measure of the relative economic impact of 5G applications in each consumer group.
Source: Analysys Mason.

Modelling scale of adoption

As discussed, the 5G enablement forecasts provided by GSMA do not provide an indication of the scale of adoption (in terms of number of firms for example) when 100% benefits are achieved. Equally, it is not immediately obvious what 10%, 20% or 50% enablement achievement translates to in terms of scale and

[31] Please see standalone Appendix B for a detailed explanation on the barrier analysis..

intensity of adoption of 5G applications. As such, a secondary piece of analysis has been conducted to provide scenarios on the asymptotic (or 'end-point') 5G adoption (at a firm level) to accompany the enablement curves provided.

The adoption curves reflect adoption relative to a notional maturity level for 5G adoption in the UK, which can be thought about as an 'addressable market'; at 100% adoption, all firms that are susceptible to adopt 5G would have done so. As such, we have developed a view on what this addressable market could be, based on adoption trends for internet and advanced technologies at different degrees of maturity (Eurostat 2020), (ONS 2018).

- an optimistic view of 5G would treat it as a general-purpose technology that could be adopted by nearly all firms, like the internet is currently
- a more nuanced view would be to look at advanced digital technologies including IoT, cloud services and 'big data', for which adoption statistics are available at UK and EU level

The scale of adoption can be expressed as % of firms by size class, and by number of employees in these firms. We have presented two addressable market scenarios by consumer group[32], based on the adoption of selected reference technologies (i.e. the Internet and IoT, cloud and big data).

The enablement curves outputs from the barrier analysis (as presented in the previous subsection) modulate adoption over time as a % of this addressable market. This is done by multiplying the total addressable market, in terms of number of employees, by the % adoption in each year on the adoption curve.

Translating addressable market to adoption curves

The cumulative benefit realised at the end of the forecast period is distributed over years in the model by the enablement curves. The addressable market gives a measure of the number of firms realising this benefit. To formulate scale of adoption scenarios, long-run addressable market scenarios have been applied multiplicatively to the enablement curve outputs for the two barrier analysis cases (i.e. Optimistic case and Central case). Where the trend for the 5G application with the highest adoption is used to represent scaling of the addressable market at the consumer group level.

6.3 Disaggregating adoption

The model carries out further calculations to breakdown 5G adoption projections by UK region, country and rural/urban area. This is achieved based on assumptions around the sub-national roll-out of a public 5G network and concurrent roll-out of private networks.

Roll-out modelling

[32] Mapping of SIC/NACE codes to Consumer Groups has been included in the analysis (See standalone Appendix D)

The sub-national profile of 5G adoption will depend, in part, of the availability of a local 5G network connection. This 5G network connection could either be provided by a public 5G network, or a private network licensed to an individual enterprise.

Public roll-out

We expect the majority of 5G adoption will be using a public 5G network. At present, the UK's public 5G network has been rolled out in a small number of urban centres. We assume the roll-out of a public 5G network will continue to follow population density, with higher population density areas receiving 5G coverage sooner than lower population density areas.

The starting assumption used in modelling of 5G roll-out are the UK-wide 5G roll-out projections obtained from Huawei and Oxford Economics study (2019). These projections (in terms of % of UK population living in areas covered by 5G) are used to calculate the increases in population living in areas with 5G coverage in each year.

For each year, the increase in population living in areas covered by 5G is allocated to the sub-regions with the greatest population density which have not yet been covered by public 5G networks. The coverage of these sub-regions is projected to increase from 0% to 100% of the regions' population. Therefore, in any given year, the UK-wide increase in population living in areas covered by 5G will be identical to the combined population of sub-regions which are projected to have 5G rolled out in the same year[33].

This step relies on high-resolution sub-regional data on population, population density and urban/rural classification:

- English and Welsh Middle-Layer Super Output Areas;
- Scottish Intermediate Zones;
- Northern Ireland's Local Authority Districts.

These data are for 2019 or 2020. It is assumed that the population density will remain the same throughout the roll-out modelling period.

The output of roll-out modelling is a table assigning the forecasted year during which 5G will be rolled out in each sub-region. This output is used as intermediate input to calculation of public network adoption described in sections below.

Private networks

Private networks have been identified as a key feature of 5G for certain types of industrial user. We thus expect a proportion of 5G adopters to use private networks, rather than public networks. However, the extent to which private networks will be utilised in future is highly uncertain, especially as at present only a handful of 5G private networks have been set-up in the UK.

Given the degree of uncertainty of the scale of future private network use, we have taken a relatively simple approach to incorporating private network assumptions into our model. We allow the user of the model to input their own assumptions around the following variables:

- The percentage of total 5G adoption among largest firms which uses private networks

[33] Subject to small difference due to rounding.

- The consumer groups that will use private networks

We assume that only the largest firms with employment of 250 and more will use private networks. As private networks will not rely on public 5G infrastructure, their availability is independent of the roll-out of public networks. Therefore, adoption of private networks by region or country is solely driven by the presence of the largest firms (250 or more employees) in certain sectors which are assumed to rely on private networks.

Roll-out and adoption of private networks are modelled simultaneously (since all firms which roll out private 5G networks will also be adopting 5G at the same time). To obtain the total UK-wide roll-out and adoption of private networks, the UK-wide adoption curves are multiplied by the addressable market assumptions and by the assumed share of private networks in 5G adoption across the largest firms.

In the next step, UK-wide adoption is distributed across regions and countries based on the presence of the largest firms in each consumer group which is assumed to rely on private networks. In any given year, the roll-out and adoption in a particular region or country are assumed to be proportional to the region or country's share in population of these largest firms which have not yet adopted public or private 5G.

The output of private network roll-out and adoption modelling is a number of employees working in firms which have adopted private networks.

Disaggregating adoption based on roll-out

Based on the expected path of public network roll-out, the model calculates the proportion of employment in firms which have access to a public 5G network in each region[34]. The UK-wide adoption curves are then disaggregated such that adoption via public route only occurs in firms with access to a public network.

The process is iterated for each year up to 2035, so that for each region the employment in firms which have access to a public 5G network and have not yet adopted is calculated. UK-wide adoption of public networks is then allocated across these regions based on their share in the total UK-wide pool of employment in firms which have access to a public 5G network.

Each adoption curve, for a given consumer group and firm size, is disaggregated in this way. For private networks, adoption can take place in areas which are not yet covered by public 5G. Therefore, the UK-wide adoption of private networks is allocated across regions based on their share in the total pool of employment in the largest firms (250+ employees).

The model then aggregates adoption across consumer groups and firm sizes to calculate total annual adoption by region or country and rural/urban area. Annual adoption in each region or country is thus determined by:

- 5G infrastructure roll-out (public networks only)
- The composition of the region in terms of consumer groups

[34] Regions available include English regions, countries (Scotland, Wales, Northern Ireland) and rural/urban areas within these.

- The composition in the region in terms of firm size

The implicit assumption underpinning regional 5G adoption disaggregation results is that the composition of consumer groups across regions will remain the same throughout the modelling period.

The output of the public network adoption modelling is a share of employment working in firms which have adopted 5G, for each region or country and consumer group.

6.4 Economic benefits modelling

The overall approach to the economic modelling can be categorised in three key stages. The model first estimates total economy impacts. The relative impacts across consumer groups are then estimated. Lastly, the sub-national impacts are estimated based on the projected sub-national distribution of 5G adoption.

The economic impact of 5G adoption is modelled as an annual GVA growth uplift over an economic baseline. It is constructed from economic forecasts generated by multisectoral dynamic modelling (CE's MDM UK model). The baseline is built up from a set of two-digit SIC code GVA forecasts mapped to the consumer groups. It is designed to provide a no-5G adoption counterfactual[35].

We follow GSMA (2019) in modelling the size of the UK-wide annual GVA growth uplift as determined by two factors: the path of 5G adoption; and an assumption of the maximum annual growth rate uplift as an impact of 5G adoption. We take a scenario-driven approach to modelling these factors, to account for the uncertainty around the future adoption and impact of 5G, which in turn is due to the lack of empirical evidence to date on which to hang a reliable forecast. The scenarios are set out in Section 7.

The model calculates relative impacts (i.e. the share of total GVA uplift that is attributable to each consumer group) based on three factors:

1. Adoption – If a consumer group adopts 5G faster and generally if 5G is more pervasive in a consumer group, then it will have a greater share of the total economic impacts attributed to it (all other things equal).
2. 5G sensitivity – The model includes the option for certain consumer groups are assumed to be more sensitive to 5G impacts. This is based on the digital intensity of the consumer groups, which reflects the extent to which a consumer group consumes digital intermediate inputs and invests in digital assets.
3. Economic size of consumer group – If a consumer group is larger in size (in terms of GVA), then it will have a greater share of the total economic impacts attributed to it (all other things equal).

Notably, the *proportional* uplift in GVA growth is determined by adoption and 5G sensitivity alone. The rationale for this is firstly that 5G has the potential to

[35] MDM treats technology as endogenous, forecasting incremental improvements in technology based on historical trends. It does not capture transformational changes to technology. As such, to construct the no-5G baseline we calibrate the MDM forecast to our incremental improvement 5G scenario, which is described in more detail in the next chapter.

lift GVA growth, and that the potential GVA uplift is shaped by the consumer group's relationship with digital technology. Potential uplift is adjusted so that the consumer groups which use existing digital technology most intensively stand to experience the most proportional gains from 5G. Specifically, this process involves constructing statistical weights which can be used to augment GVA uplift. The calculations are shown below, where i is the consumer group, ω is the statistical weight, $GFCF$ is gross fixed capital formation, Z is intermediate demand (i.e. demand for supplies/support services) and ΔGVA is the change in GVA.

$$\omega_i = \begin{cases} 0.5\frac{GFCF_{i,digital}}{GFCF_{i,total}} + 0.5\frac{Z_{i,digital}}{Z_{i,total}}, \text{if digital total} \\ \frac{GFCF_{i,digital}}{GFCF_{i,total}}, \text{if digital investment} \\ \frac{Z_{i,digital}}{Z_{i,total}}, \quad \text{if digital demand} \end{cases}$$

$$\Delta GVA_i = \omega_i \Delta GVA_{i,initial} \times \frac{\sum_i \Delta GVA_{i,initial}}{\sum_i \omega_i \Delta GVA_{i,initial}}$$

This manipulation is muted under the "Digital balanced" scenario assumption.

Next, adoption shapes the extent to which the potential gains from 5G are realised. Consumer groups which adopt 5G most rapidly are able to accelerate GVA growth earlier and by a greater extent. Total addressable market assumptions also affect the GVA uplift experienced in the ADT scenario (under GPT total addressable market is proportionate across all consumer groups).

Lastly, the GVA uplift is applied to the respective activities within each consumer group. For a given GVA growth uplift, consumer groups which include a larger amount of economic activities (such as Smart Urban) therefore generate larger GVA benefits.

Sub-national economic impacts are calculated using the intermediate outputs from the adoption disaggregation module described in Section 6.3. The starting point in disaggregating economic benefits by region or country is the region or country's share in total UK employment working in firms which have adopted 5G, for each consumer group.

In the next step these shares are converted using sub-national GVA data to sub-national shares in total UK GVA attributable to employment working in firms which adopted 5G. This conversion allows the model to account for sub-national differences in GVA per employee. Therefore, the estimated economic impact in region A for any given consumer group is calculated as:

$$\begin{aligned} &Economic\ impact\ in\ region\ A \\ &\qquad = UK\text{-}wide\ GVA\ impact \\ &\qquad * \frac{Region\ A's\ GVA\ attributable\ to\ firms\ which\ adopted\ 5G}{UK\text{-}wide\ GVA\ attributable\ to\ firms\ which\ adopted\ 5G} \end{aligned}$$

A similar approach is used to calculate sub-national impacts of private networks adoption. These impacts are assumed to be proportional to employment working in firms which adopted private 5G networks, expressed as a share of total employment working in firms which adopted 5G.

6.5 Environmental benefits modelling

Environmental benefits are modelled as additional emissions avoided due to adoption of 5G-enabled over 4G for a range of use cases. The avoided emissions factors are obtained from GSMA (2019), which estimated avoided emissions factors from various mobile network enabled technologies in 2018. Avoided emissions factors represent a net impact on emissions, considering the avoided emissions, as well as the emissions associated with the use of mobile-technology-enabled alternative. The additional avoided emissions from using 5G are calculated by applying additionality factors used in Accenture (2019) to conduct a similar exercise for Canada.

These avoided emissions factors cover a range of IoT machine to machine use cases and smartphone use cases. The way in which 5G use leads to emissions savings depends on the type of use case:

- IoT machine to machine use cases such as those in buildings, transport, manufacturing, and the energy sector, will enable emissions savings through improved efficiency.
- In addition, smartphone 5G use cases will enable emissions savings through behavioural changes (e.g. more online shopping, use of transport apps increased public transport use, etc,).

For each of the use cases for which avoided emissions factor data are available, the model calculates avoided emissions by projecting the number of 5G connections linked to that use case and applying the avoided emissions factor.

The number of IoT machine to machine connections in the UK is estimated by taking the GSMA-estimated number of connections in Europe in 2018 and scaling it using a ratio of UK to European GVA in each consumer group. The number of devices is then projected up to 2035 assuming the same growth rate as the baseline economic growth projections.

The number of smartphone connections linked to the use cases derived from GSMA (2019) is projected forward by extrapolating Analysys Mason's in-house projections on the number of smartphones, or using baseline economic growth projections (IoT machine to machine use cases).

We calculate avoided emissions under the assumption of additionality of 5G compared to its predecessors. This approach follows Accenture (2019), in which 5G multipliers were assumed to result in additional avoided emissions enabled by 5G-enabled features. As in the Accenture study, we set the upper case for 5G additionality at 90% improvement, and the lower case at a 40% improvement. Therefore, the estimated impacts can be interpreted as the incremental reduction in emissions brought by 5G-enabled features of various mobile network technologies.

It is worth noting that we have not explicitly modelled the environmental impact of increased economic activity resulting from 5G adoption. It is reasonable to expect that higher economic output stimulated by 5G could increase emissions. To model this type of effect would require emissions estimates directly linked to economic impact estimates, which we do not attempt to model here.

6.6 Social benefits modelling

Our literature review of the social impacts of 5G found numerous potential benefits. However, the nature of many social impacts (health, wellbeing, quality of life etc.) make them difficult to quantify, with only a small number of bottom-up literature attempting to do so for specific use cases of interest.

For this reason, we focus on quantifying the social benefits for only a specific use case – time savings from adoption of IoT technologies by individual consumers. This was the use case for which the most robust evidence was available, considering factors including availability of empirical data and evidence of additionality. We anticipate that as more data become available in future, it will be feasible to quantify the social benefits of other use cases following a similar approach.

The calculation of UK-wide time savings due to adoption of 5G-enabled IoT technologies is based on various parameters. The following formula was used to estimate the annual time savings (in hours):

$$\begin{aligned} Annual\ time\ saved\ (hours) &= \ 5G\ adoption\ rate * IoT\ time\ saving\ rate \\ &* 5G\ Additionality\ factor * \\ &* Average\ time\ spent\ on\ household\ and\ family\ care\ per\ adult \\ &* Adult\ population\ projection \end{aligned}$$

The 5G adoption rate is taken from the adoption and barriers model as an adoption curve for ‘High-speed broadband into homes and offices’ consumer group, which is assessed to best represent the adoption of personal and household 5G IoT devices. The assumption on the IoT time savings rate (17%) is taken from McKinsey study (2015). To reflect 5G additionality in the estimate, only 5% of these time savings from IoT applications are attributed to 5G. This additionality factor is based on the lower-end parameter used in the European Commission (2016) study. Other parameters used in the calculation include the average time spent on household and family care per adult in the UK (from Eurostat) and UK adult population projections (from the ONS).

To obtain the monetary value of time saved, the estimated annual time savings in hours are multiplied by the estimated value of time obtained from the economic literature. The estimate was sourced from a study on the Willingness to Pay (WTP) for leisure traded against unpaid work (Verbooy, et al. 2018). After applying currency conversion and inflation adjustment, this value stood at £8.10 per hour (2018 prices).

The values of estimated social impacts produced by the model (time saved and its value) are directly proportional to the values of parameters outlined in the equation above. Therefore, any uncertainty around the value of these parameters leads to a directly proportional degree of uncertainty around the estimated impacts. For example, the 5G additionality parameter, at 5%, is taken as a lower end estimate from the European Commission study (based on the enhanced real-time capabilities and connectivity to the cloud offered by 5G wearable devices). However, the potential additionality of 5G to home and consumer could be as high as 10%, if based on a parameter from the same study (additionality of enhanced 5G-enabled real-time data exchange capabilities of smart meters). This means that the estimated time savings and their value could double if the alternative value of 5G additionality parameter was used.

Similarly, alternative sources estimate the time saving rate of personal and household IoT devices at 20% (AT Kearney 2016). Use of this rate (instead of the assumed 17%) would increase the estimated time savings and their value by approximately 9%. This demonstrates a large degree of uncertainty in the estimated social impacts.

6.7 Challenges and limitations

It is important to note that modelling future impacts of 5G adoption is a challenging exercise due to the complexity of the task and the high level of uncertainty, in part due to a lack of empirical evidence. Compared to previous mobile broadband standards, 5G is supposed to enable a wider range of use cases and applications. However, 5G is a relatively new technology that is only just beginning to be rolled out in the UK and around the world. This means there are very few empirical data on the roll out, adoption and application of 5G. The absence of empirical data on how 5G is being used and by whom, and the scale and nature of benefits associated with that makes it difficult, if not impossible, to populate the model with data and parameters based on real world experience.

Existing studies have attempted to estimate the overall impact or benefit of 5G. However, faced with the same data limitations, these studies all provide ex ante estimates which either rely on assumptions about the nature and scale of the adoption of 5G and the benefits it brings; or draw on the empirical evidence on the evolution and impact of previous technologies, such as 4G, to approximate or make assumptions about how 5G will be adopted and the benefits it will bring.

Both approaches have limitations. Studies based on the impacts of previous technologies can use robust estimates of these impacts but are restricted by the assumption that 5G is comparable to previous technologies. Studies which forecast the impact of 5G based purely on expert assessment can assume that the impact of 5G will be more transformative, but such forecasts are highly subjective. The trade-off between the extent to which these studies are grounded in empirical data and the extent to which they consider the specifics of 5G reflects the limited evidence base – a challenge we are also faced with. Without sufficient data to estimate our own model relationships, we will have to rely on estimates and assumptions from these studies to develop the model parameters.

A further challenge of identifying the benefits of 5G is additionality – determining the extent to which each benefit can be attributed to 5G. This is difficult because many of the 5G use cases are also at least partly functional with 4G or other internet technologies – making the benefit from 5G incremental and hard to isolate. Backward-looking studies, such as those estimating the impacts of earlier technologies, can overcome the additionality problem through well designed identification strategies. Forward-looking studies do not have this luxury. Some studies attempt to address additionality by focusing only on use cases for which 5G is critical, while others apply an estimate of the degree of additionality, to scale down their impact estimates. Many studies make no attempt to address additionality.

We aim to address the additionality problem as far as possible by utilising estimates of earlier technology impacts, available estimates of additionality factors, and a scenario-driven approach. Nevertheless, some results from the model will need to be carefully interpreted with respect to their degree of additionality based on our own knowledge of the use cases and the extent to which they are enabled by 5G.

Considering the challenges that we have set out, the model has been designed to break down the distribution of the benefits across consumer groups, households and firms, and geographical areas. In doing this, the model meets fills an evidence gap that is important for policymakers to address. It also allows us to ground the model in data and assumptions around relatively impacts that we can be more confident about. The scale of the impacts of 5G are highly uncertain, but the likely relative impacts of 5G will be driven, to some extent, by the profile of 5G adoption among consumer groups and geographical areas.

7 Scenario descriptions

This chapter describes the scenarios for 5G adoption and impact that we have developed and for which model results are presented in this report. Note that a key feature of the model is that the user can build their own scenarios by varying many of the model parameters. The scenarios we present have been constructed based on our own assessment of the potential nature of 5G adoption and impact based on the literature, evidence captured in this study and our own analysis.

7.1 5G adoption and impact scenarios

We present results for two adoption and impact scenarios:

- an optimistic view of 5G would treat it as a general-purpose technology (GPT) that could be adopted very pervasively across a wide range of economic activities, like the internet is currently;
- a more nuanced view would be to look at advanced digital technologies (ADT) including IoT, cloud services and 'big data', for which adoption statistics are available at UK and EU level.

For each of these scenarios we have developed addressable market and GVA uplift assumptions. The addressable market assumptions are based on analysis of adoption trends for internet and advanced technologies at different degrees of maturity. These scenarios are described in Table 7.1 below:

Table 7-1: Addressable market scenarios

Scenarios	Long-term 5G adoption - technology reference	Adoption scale asymptote (2035)
Scenario 1: 5G as a ubiquitous / General Purpose technology	Similar to the adoption of mobile internet by firms for business purposes	70% of all firms, with most non-adopter firms likely to be micro/small enterprises.
Scenario 2: 5G as an advanced digital technology	5G follows IoT and Cloud adoption trends	60-75% of medium to large firms (50+ employees) 30-35% for smaller firms (10+ employees). Adoption varies across consumer groups.

Alongside the assumptions of addressable market, GVA uplift assumptions have been developed for each of the GPT and ADT scenarios. The GVA uplift scenarios were informed by a focussed review of evidence relating to 5G, incremental improvements in mobile internet (or related technologies) and general purpose technology. Due to sensitivity in the scoped evidence (and incomplete information regarding underpinning assumptions), a degree of judgement was necessary to determine the adopted GVA uplift assumptions.

For the GPT scenario, GSMA (2018) paper's assessment of a maximum potential uplift of economic growth stemming from 5G (0.28 pp) was used as an impact ceiling in the model. This finding was also echoed by other literature. CIE (2014) estimated ex-post that the productivity impacts of mobile broadband sector as a whole was 0.28 pp. Lastly, the median impact across the collated range of GPT studies roughly equalled 0.28 pp (but is very sensitive to the selection and organisation of study findings).

For the advanced digital technology scenario, we drew on existing studies which include high/low impact estimates of 5G (or of related technology). This includes Productivity Commission (2004) and, notably, Australian Government (2018) which indicates that the GVA uplift from a more incremental type of improvement in mobile technology is around four times lower than in the GPT scenario (although we adopt different assumptions about GVA uplift intensity and timing). The median findings of papers which estimate impacts of incremental changes in mobile technology were also used to inform the estimate. The median growth uplift of incremental technological change was also found to be around 4-times lower than that of GPT. Hence, for this scenario we set the maximum GVA uplift to 0.07pp.

7.2 Market barrier assumptions

As explained in the previous chapter, the 5G adoption curves in our model can be varied across different demand-side market barrier assumptions. Demand-side barriers could have an impact on both the timing (i.e. a delay in adoption starting) and rate of adoption (i.e. a slower adoption over time). We model impacts under each of the two adoption and impact scenarios for two separate sets of market barrier assumptions:

1. Central case: For each consumer group we have assessed the extent to which market barriers are expected to impact 5G adoption over the modelling period. From this assessment, which draws on evidence from literature and evidence gathered during this study, the delay to adoption and rate of adoption ratings have been set by Analysys Mason.

2. Low case: In this case all barriers that could be addressed through proactive Government policies[36] are addressed, barring those we expect to be largely dependent on market choices, i.e. 'Cultural resistance to change' and 'Existing technologies are seen as sufficient'. Additionally, we have included the impact of a barrier which may be partially addressed through the market and partially addressed through government initiatives, i.e. 'Ecosystem not ready'.

These projections have been calibrated by referencing 'digital readiness assessment' outputs (see Figure 4-6). Relative timeline of adoption for various consumer groups was sense-checked as well as the timeliness of adoption forecasts at a 5G application level. For example:

[36] It is noted that proactive industrial policies might also address some of the barriers cited e.g. by proactively addressing the lack of understanding over 5G benefits.

- Earlier adoption of 5G is driven by eMBB supported use cases, (e.g. FWA and MBB for homes and offices, AR/VR) and further enabled through edge-cloud capabilities
- Emerging adoption is expected to be driven initially by use of 5G for IoT use cases as well as automation/ robotics thereafter
- Lagging adoption is expected for those consumer groups and use cases dependent on advanced technology adoption or affected by supply-side barriers such as coverage

7.3 Comparing results across scenarios

The results discussed in the following chapter are based on, in effect, the impacts of 5G adoption under four scenarios: two scenarios of potential adoption and impact each modelled with two sets of market barrier assumptions.

The model results under the central market barriers case are presented as our headline projections of 5G impact in the GPT and ADT scenarios, because these results represent our assessment of the likely impact of market barriers on each consumer group. Modelling the GPT and ADT scenario under low market barrier assumptions is used to estimate the potential value of removing all demand-side market barriers. This demonstrates how the model can be used to assess the potential value of removing market barriers under different adoption scenarios. Table 7-2. below illustrates how the model is used to project the impact of removing market barriers:

Table 7-2.: Model scenarios

	5G as a GPT	5G as an advanced digital technology
Central market barriers assumption	Scenario 1	Scenario 3
Low market barriers assumption	Scenario 2	Scenario 4
Value of removing market barriers	Scenario 2 - Scenario 1	Scenario 4 - Scenario 3

While this report focuses on the potential gains from removing all demand-side market barriers, policymakers working on solving specific market barriers will be also be interested to model the marginal impact of removing such market barriers while holding all other market barriers constant. It is hence important to note that the model can be used to do this, both to model UK-wide impacts and to model impacts within a given consumer group.

8 Analysis of scenario results

8.1 General introduction

What determines economic impacts in the 5G model?

As a general rule, the modelling of economic impacts considered (and can be explained by) the following dynamics and scenario features:

1. **Core uplift** – The nature of change that will be induced by 5G in the next 15 years is not fully understood and a range of hypotheses are present in the literature. The core impact of 5G varies depending on whether it is assumed to be a general purpose technology or whether it is assumed to have more conservative impact potential (e.g. akin to IoT or cloud computing).
2. **Adoption** – Adoption determines the extent to which potential economic impacts are realised. Faster and greater adoption will lead to greater economic impacts of 5G.
3. **Barriers** – Presence of market barriers affect adoption and, therefore, economic impacts. This feature in particular highlights the role of policy in facilitating the economic benefits of 5G.
4. **Addressable market** – The proportion of the total market which can realistically be addressed by 5G will determine its economic impacts. This is of particular interest when contrasting impacts across consumer groups.
5. **Baseline size of consumer groups** – Some defined consumer groups are very large in size, because they capture a large range of economic activities and/or the UK economy has specialised in the sectors they correspond to (e.g. finance and professional services). Larger sectors have a greater impact in levels terms all other things equal, because of their relative importance to the UK economy.

In the discussion of consumer-group impacts, we also consider the impact of introducing digital intensity to model variation in marginal impact of 5G adoption between consumer groups:

6. **Digital intensity** – Some defined consumer groups have a greater digital element to their economic activity. A large share of their investment may be made into digital-related capital, or a large share of goods and services necessary to support their activities may be demanded from digital-related sectors. In some scenarios, this is taken into account and therefore affects the relative impacts across consumer groups.

For sub-national impacts, three further variables influence the model results:

7. **Public network roll-out** – We model 5G roll-out as starting in high population density area and gradually reaching lower population density areas.

8 **Regional composition of consumer groups**[37] – The types of consumer groups which exist in different UK geographies will affect the distribution of impacts across the UK.

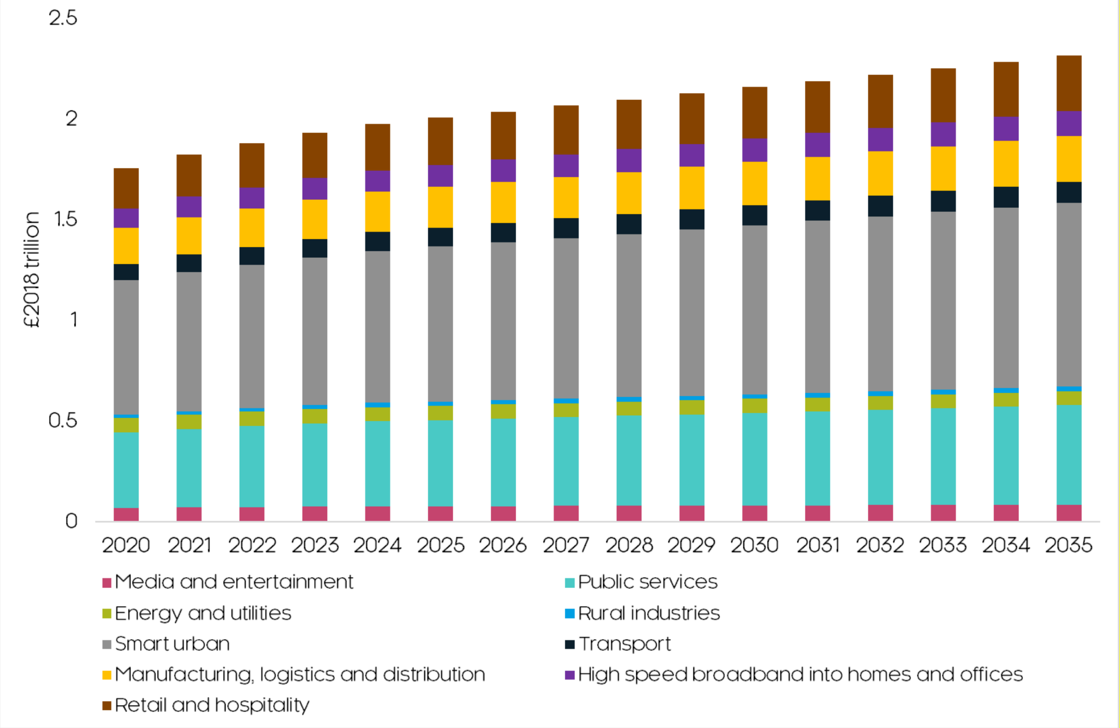
9 **Spatial firm demographics –** The firm demographics (i.e. composition of large and small firms) across UK geographies will affect the distribution of impacts across the UK.

UK baseline assessment

As a part of the modelling exercise, a baseline forecast for the UK economy was required. This was principally[38] derived from Cambridge Econometrics' Multisectoral Dynamic Model of the UK economy[39]. This is shown in Figure 8-1.

The overall growth rate of the UK economy in the baseline is 1.9% pa over 2020-2035. Across consumer groups, it can be seen that Smart Urban and Public Services are the largest in GVA terms in the model baseline.

Figure 8-1: Model baseline (UK GVA by consumer group)



Sources: Cambridge Econometrics calculations, Analysys Mason Calculations, MDM-E3 econometric model, ONS Supply and Use Tables.

8.2 Economic impacts

This section presents the aggregate model results for the UK as a whole, across all sectors and geographies. This provides a high-level assessment for the potential benefits 5G could bring to the UK economy.

3737

[38] A fuller description of the process to estimate the baseline provided in the model description note..

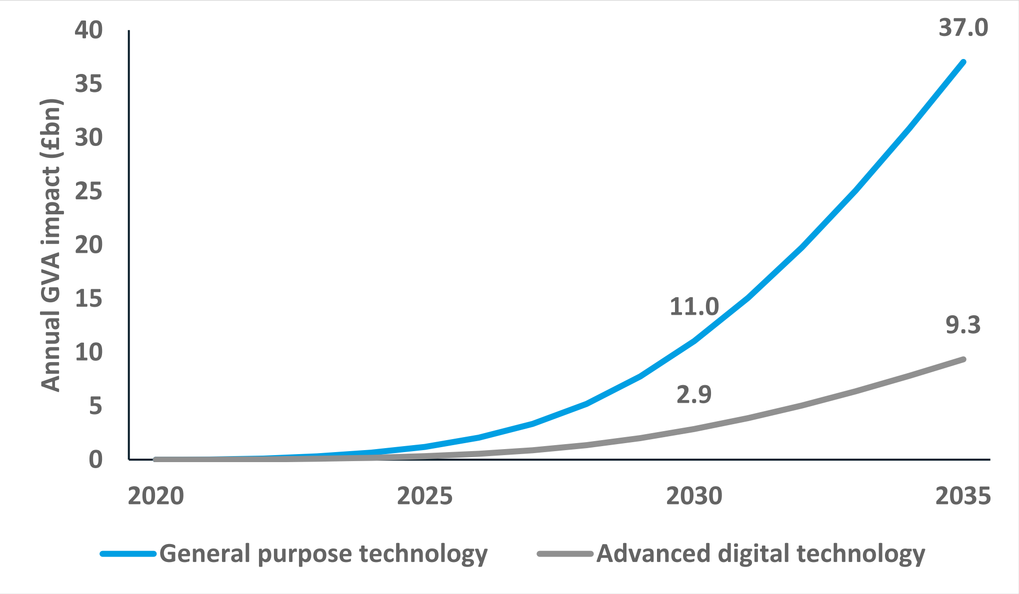
[39] https://www.camecon.com/how/mdm-e3-model/

5G technology is projected to generate £41bn - £159bn in GVA over 2021-35

In the general-purpose technology scenario, where adoption is widespread across consumer groups and firm sizes, the cumulative economic impact of 5G adoption over 2021-35 under the central market barriers case is projected at £159bn, reaching an annual GVA benefit of £37bn in 2035. In the advanced digital technology scenario, GVA benefits are smaller (£40.7bn cumulative over 2021-35; £9.3bn in 2035), reflecting the more conservative scenario assumptions (see Chapter 4). The trends in annual GVA impacts across these two scenarios are shown in Figure 8-2.

When expressed in relative terms, this result implies that UK GVA across all sectors of the economy is on aggregate 1.6% higher as a result of 5G under the GPT scenario and 0.4% higher under the ADT scenario.

Figure 8-2. Aggregate GVA impacts of UK-wide 5G adoption (central market barriers case), 2021-35

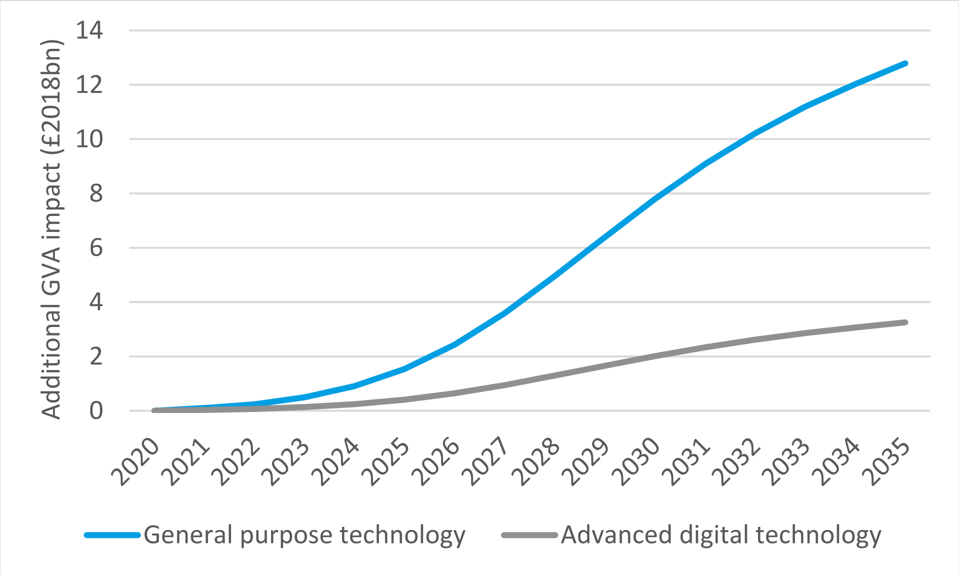


Notes: Annual GVA impacts of 5G (£bn) are shown for the general purpose technology (GPT) and advanced digital technology (ADT) scenario assumptions (central market barrier).
Sources: Cambridge Econometrics calculations, Analysys Mason Calculations, MDM-E3 econometric model, ONS Supply and Use Tables.

Economic benefits could be extended by up to £84bn over 2021-35 if market barriers are addressed

The result above assumes a central case of market barriers to 5G adoption, based on the outputs of the barrier assessment (see standalone Appendix B). Under a more optimistic, low barrier scenario, impacts could be much higher. Over 2021-35, it is projected that 5G benefits could be extended by a further £84bn under the GPT scenario (£22bn under the ADT scenario) if efforts are made to reduce barriers to adoption of 5G, highlighting the importance of policy in realising 5G benefits. The annual additional benefits across general purpose technology and advanced digital technology scenarios are shown in Figure 8-3.

Figure 8-3. Additional GVA impacts of UK-wide 5G adoption from lower market barriers, 2021-35



Sources: Cambridge Econometrics calculations, Analysys Mason Calculations, MDM-E3 econometric model, ONS Supply and Use Tables.

This section presents the model results broken down by individual consumer groups. This illustrates the sectoral areas of the UK economy which benefit the most from 5G (and are most affected by the market barrier conditions which affect adoption).

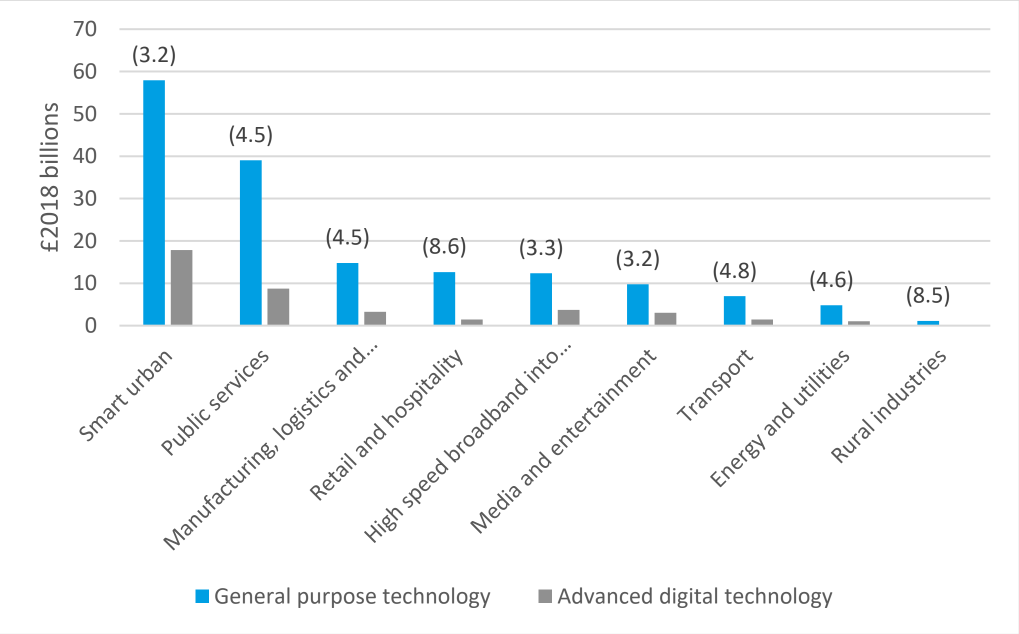
5G will have the greatest impact on the Smart urban consumer group in terms of £s of GVA

Figure 8-4 below compares the projected cumulative GVA impacts over 2021-35 in each consumer group in the GPT and ADT scenarios (the relative impacts of the general purpose technology relative to advanced digital technologies is shown in brackets). The cumulative economic impact of 5G adoption over 2021-35 under the central market barriers case is projected at £58bn for Smart urban, £39bn for public services and £15bn for Manufacturing, logistics and distribution, in the General Purpose Technology scenario. These three sectors have the largest (levels) benefits for two main reasons:

- **Size** – The (baseline) industrial composition of the UK economy is such that Smart urban, Public services and Manufacturing, logistics and distribution consumer groups are considerably larger than others (especially Smart urban). Collectively, these three consumer groups make up more than 2/3 of UK economic activity in GVA terms. A given change in GVA will therefore create greater levels impacts in these consumer groups.
- **Adoption** – Benefits are also higher in the selected consumer groups because 5G adoption is faster than some other sectors (with the exception of Media and entertainment and High speed broadband in homes and offices). In particular, adoption is especially rapid in the Public services consumer group, adopting almost twice as fast as Retail and hospitality (slowest adoption). This is largely driven by the kind of applications 5G will enable and the relevance of these applications to each consumer group's activities.

In the advanced digital technology scenario, the size of the impacts are consistently smaller (as per scenario assumptions) but the extent to which ADT impacts are lower varies depending on consumer group, ranging from 3.6 times larger (Smart urban) to 8.6 times larger (Retail and hospitality). The principal reason for this variation across consumer groups relates the assumed addressable market. The GPT scenario assumes by definition that the technology is general in nature and the same market share is addressable in all consumer groups. The ADT scenario is more pessimistic about the potential addressable market, especially in retail and hospitality and rural industries.

Figure 8-4. Cumulative GVA impacts of 5G adoption by region and country (central market barriers case), 2021-35



Sources: Cambridge Econometrics calculations, Analysys Mason Calculations, MDM-E3 econometric model, ONS Supply and Use Tables.

5G adoption will positively impact GVA in all consumer groups, but to varying extents

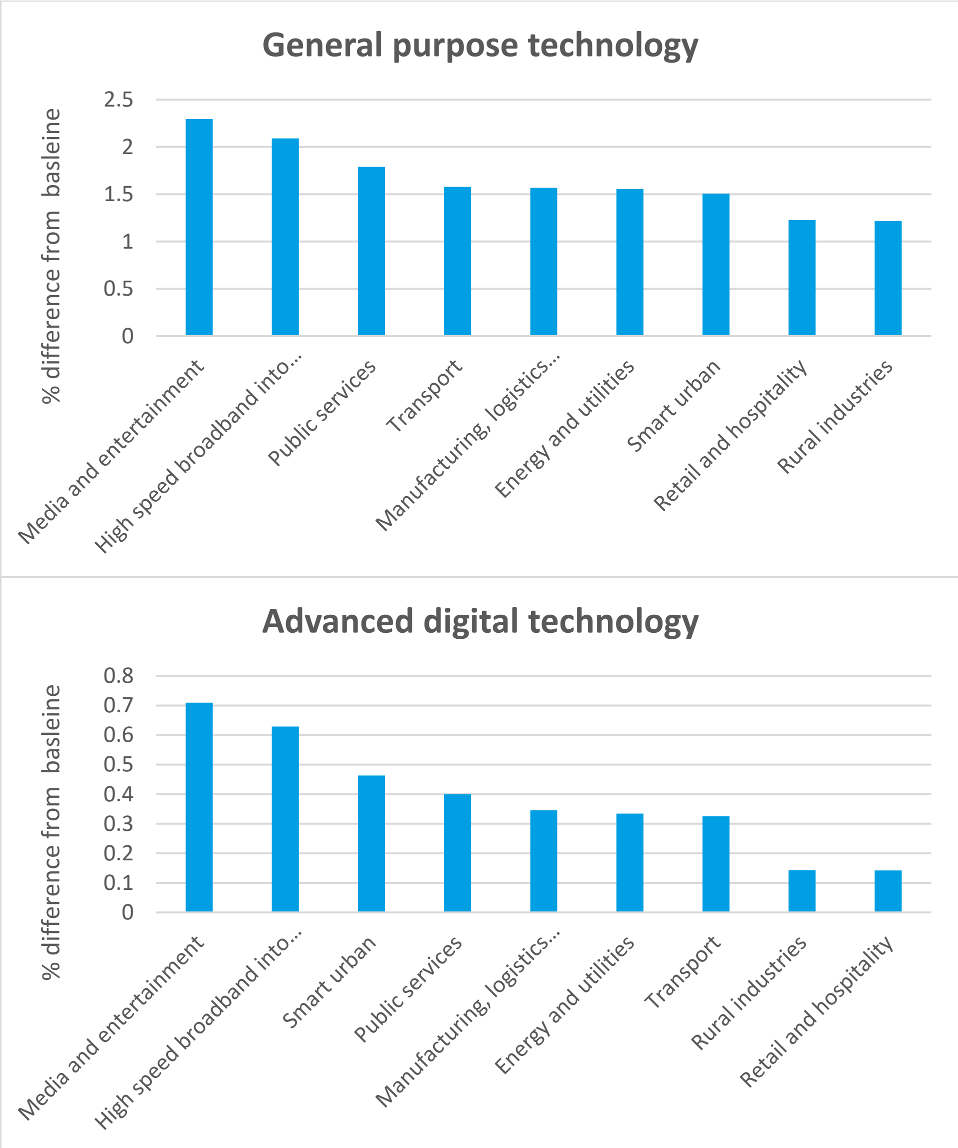
Figure 8-5 charts the projected difference in GVA in 2035 from the no-5G baseline for UK regions and countries in the GPT and ADT scenarios under the central market barriers case. In the GPT scenario, impacts range from 2.3% in Media and entertainment to 1.2% in Rural industries, while in the ADT scenario impacts range from 0.7% to 0.1%.

Variation between consumer groups impacts is mainly driven by the rate of (and delays to) adoption. Media and entertainment and High speed broadband in homes and offices are the fastest consumer groups to adopt 5G (both counting as “early adopters” in AM report). This is due to eMBB supported use cases (such as connectivity, UHD, AR/VR) and early adoption of IoT use based on sensor network use cases.

Slow adoption is also the main reason that Retail and hospitality and Rural industries have lower proportional impacts (relative to the baseline). In the case of Retail and hospitality, a key driver of lukewarm adoption is issues in understanding the business case or return on investment for sensor network collation. This is further exacerbated by perceived competition with existing technologies (fibre/4G/Wi-Fi). In the case of rural industries, this is principally due to supply side issues (i.e. lack of mobile coverage).

For the ADT scenario, impacts are also affected by addressable market assumptions. Rural industries and Retail and hospitality consumer groups have especially low addressable market shares (for similar reasons as weak adoption, described above) and GVA impact are therefore especially dampened.

Figure 8-5. Impact of 5G adoption on GVA in 2035 by region and country (% difference from baseline), central market barrier case



Three consumer groups emerge as having the most to gain from the removal of market barriers

The consumer group results thus far have only considered the impacts associated with a central scenario for market barriers. When additional benefits associated with lowering market barriers are considered, three consumer groups emerge as having the most to gain from the removal of market barriers:

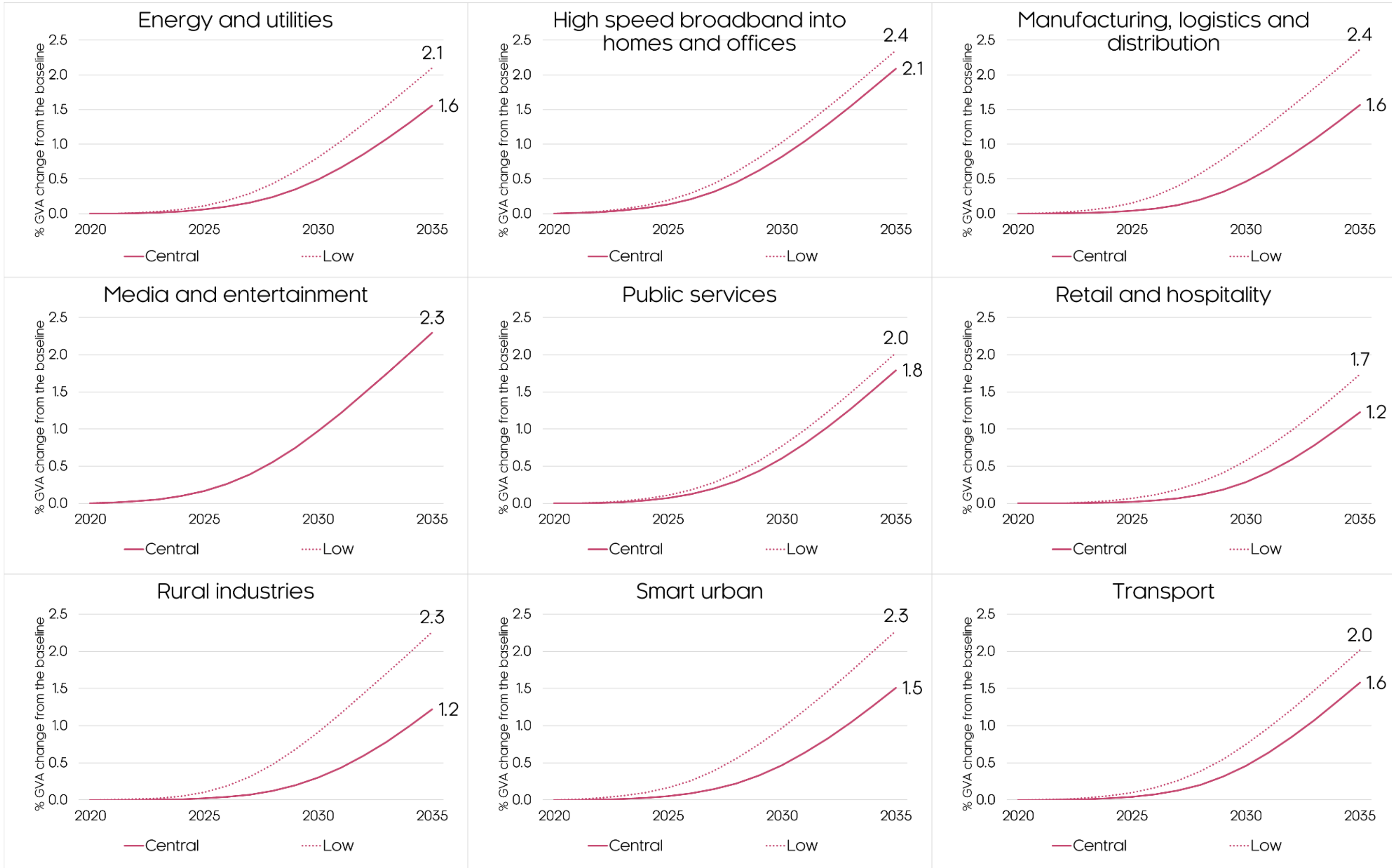
- **Manufacturing logistics and distribution** – Feasible reductions in barriers are fairly even across 5G applications, however a reduction in remote object/machine manipulation is of particular importance given the relative importance this has to the consumer group's activities and the extent to which this 5G application is delayed by market barriers.

- **Smart urban** – Also attributed to a range of 5G applications. Of particular interest are market barrier reductions for sensor networks, because this application is particularly relevant to Smart urban activities.
- **Rural industries** – Market barriers create especially large delays for remote object/machine manipulation and smart tracking 5G applications.

From a policy perspective, these are the consumer groups whose benefits depend most on action taken to reduce market barriers to 5G adoption. For example, the manufacturing consumer group has the potential to have one of the most rapid adoption pathways and, under the right conditions, could experience a 2.4% boost to GVA relative to the baseline in 2035. However, if market barriers are not addressed then adoption will be delayed and benefits will be considerably smaller.

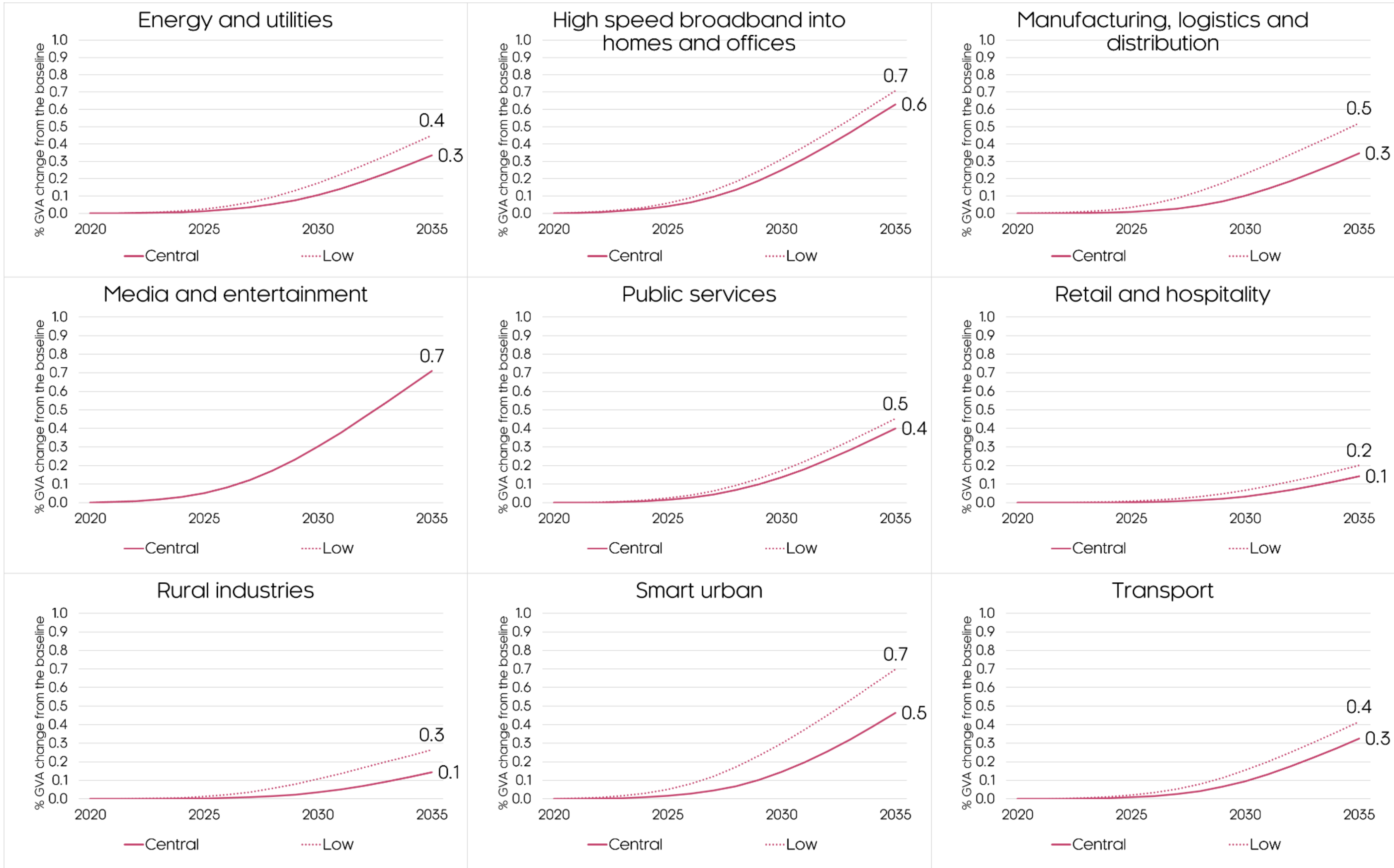
Media and entertainment has the same GVA impact trajectory both in the central scenario and in the scenario with lower market barriers. This is because in the central case there are already no market barriers dampening or delating adoption (see Chapter 5 on market barrier assessments). Another implication of this is that there are no additional benefits of removing market barriers. Figure 8-6 and Figure 8-7 show how GVA impacts (% difference from the baseline) is affected by market barriers across all consumer groups.

Figure 8-6. GVA impacts by consumer group relative and barrier scenarios (% difference from baseline, GPT assumption, 2021-35)



Sources: Cambridge Econometrics calculations, Analysys Mason Calculations, MDM-E3 econometric model, ONS Supply and Use Tables.

Figure 8-7. GVA impacts by consumer group relative and barrier scenarios (% difference from baseline, ADT assumption, 2021-35)



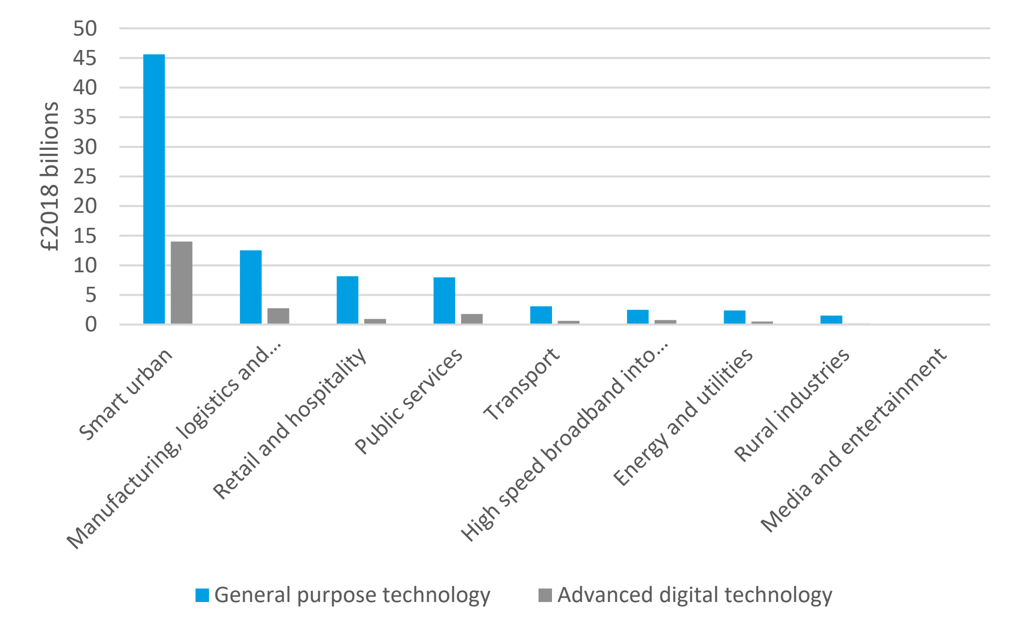
Sources: Cambridge Econometrics calculations, Analysys Mason Calculations, MDM-E3 econometric model, ONS Supply and Use Tables.

69-77% of extended benefits from lowering market barriers are in Smart urban or Manufacturing consumer groups

Figure 8-8 shows the additional GVA levels benefits from lower market barriers over 2021-35 (cumulative). When accounting for differences in consumer group size, the potential gains from addressing market barriers in Smart urban and Manufacturing logistics and distribution becomes even more notable. Rural industries additional benefits are smaller in levels terms because of the size of the sector.

Lowering market barriers to 5G in these two consumer groups alone would extend cumulative (2021-35) benefits by £58bn under the GPT scenario (£17bn under ADT). This implies that 69-77% of the benefits of lowering market barriers are attributable to Smart urban or Manufacturing sector.

Figure 8-8. Additional GVA levels impact over baseline in 2035 from removing 5G market barriers across consumer groups (difference between low market barrier case and central market barrier case)



Sources: Cambridge Econometrics calculations, Analysys Mason Calculations, MDM-E3 econometric model, ONS Supply and Use Tables.

To understand what is driving this result, it is helpful to examine both tails of the results. At the upper tail, Smart urban has a very large impact due to the combination of very large baseline GVA (highest of all consumer groups) and also high addressable market share and change in market barriers across central and barrier assessment scenarios.

At the lower tail, despite having the highest total addressable market (under ADT), Media and entertainment contributes 0% of the benefits of lowering market barriers. This is because there no market barriers which can be feasibly removed from the central estimate. In a similar vein, despite removable market barriers being very high, Rural industries contributes a small share of additional benefits because of low addressable market share and a very low baseline GVA. The ranking of consumer groups across factors which affect these extended benefits are shown in Table 8-1.

Table 8-1: Ranking of consumer groups across factors which affect extended benefits

	Market barrier change	Baseline size	Addressable market (only affects ADT)
Media and entertainment	9th	8th	1st
Public services	8th	2nd	4th
Energy and utilities	4th	7th	6th
Rural industries	1st	9th	8th
Smart urban	3rd	1st	2nd
Transport	6th	6th	7th
Manufacturing, logistics and distribution	2nd	4th	5th
High speed broadband into homes and offices	7th	5th	3rd
Retail and hospitality	5th	3rd	9th

Notes: Market barrier change refers to the pp change in adoption rates which are attributable to differences in market barriers between the central scenario and the barrier assessment scenario; Baseline size refers to the relative GVA size of the consumer groups under the baseline; Addressable market refers to the total addressable market share of the consumer group (under ADT). All numbers refer to the ranking (e.g. Smart urban has the largest baseline size, Rural industries have the smallest).

Sources: Cambridge Econometrics calculations, Analysys Mason Calculations, MDM-E3 econometric model, ONS Supply and Use Tables.

Figure 8-9 contains a matrix that indicates based on manipulation of the intermediate model inputs which barrier reductions are most important for boosting economic benefits. Specifically, the calculations comprised multiplication of: (1) 5G feature relevance (by consumer group and feature); (2) the differences in delay and adoption-rate parameters between central and low barrier scenarios; and (3) relative economic size.

The findings indicate that removal of the market barriers holding back adoption of sensor networks and remote object / machine manipulation in the Smart urban and Manufacturing, logistics and distribution consumer groups could bring the greatest economic benefit.

The key market barriers holding sensor network adoption back for these consumer groups are: security concerns; lack of business case / understanding of return on investment (ROI); lack of understanding of total cost of ownership (TCO) / concern over ongoing costs/monthly data costs; and concern over upfront (capital) costs.

Market barriers to remote object / machine manipulation are also important in realising 5G benefits. In contrast to sensor networks, a key challenge of remote object / machine manipulation is that the ecosystem is not yet ready or made available. Adoption of object/machine manipulation is also held back by a lack of understanding of 5G and the benefits that it offers.

Figure 8-9: Matrix of relative importance (potential market barrier reductions, relevance of 5G features and economic size)

	Media and entertainment	Public services	Energy and utilities	Rural industries	Smart urban	Transport	Manufacturing, logistics and distribution	High speed broadband into homes and offices	Retail and hospitality	Total
AR/VR	0.0	1.8	0.2	0.2	0.0	0.0	0.0	0.0	6.6	8.8
UHD video	0.0	4.7	0.0	0.0	2.1	0.3	0.0	0.0	0.6	7.7
High-speed broadband	0.0	2.4	0.0	0.2	4.2	1.0	0.0	2.4	0.6	10.9
Sensor networks	0.0	0.0	1.6	0.5	21.0	0.8	3.9	0.0	3.2	31.0
Remote object/machine manipulation	0.0	0.0	1.0	0.3	16.8	0.0	5.1	0.0	0.0	23.3
Robotics	0.0	0.0	0.7	0.0	5.3	0.0	1.7	0.0	0.0	7.6
Connectivity for 5G drones	0.0	0.0	0.0	0.1	0.0	0.0	1.1	0.0	0.0	1.3
Smart tracking	0.0	0.0	0.0	0.1	0.0	1.3	2.5	0.0	0.0	3.9
Connectivity for autonomous/connected vehicles	0.0	0.0	0.0	0.0	4.2	0.5	0.8	0.0	0.0	5.6
	0.0	8.9	3.5	1.5	53.7	3.8	15.2	2.4	11.1	100.0

Notes: The values reported in the matrix are components of an index (which sums to 100) and do not have any direct interpretation other than indicating the *relative* economic significance of barrier reductions across 5G features and consumer groups.
Sources: Cambridge Econometrics calculations, Analysys Mason Calculations, MDM-E3 econometric model, ONS Supply and Use Tables.

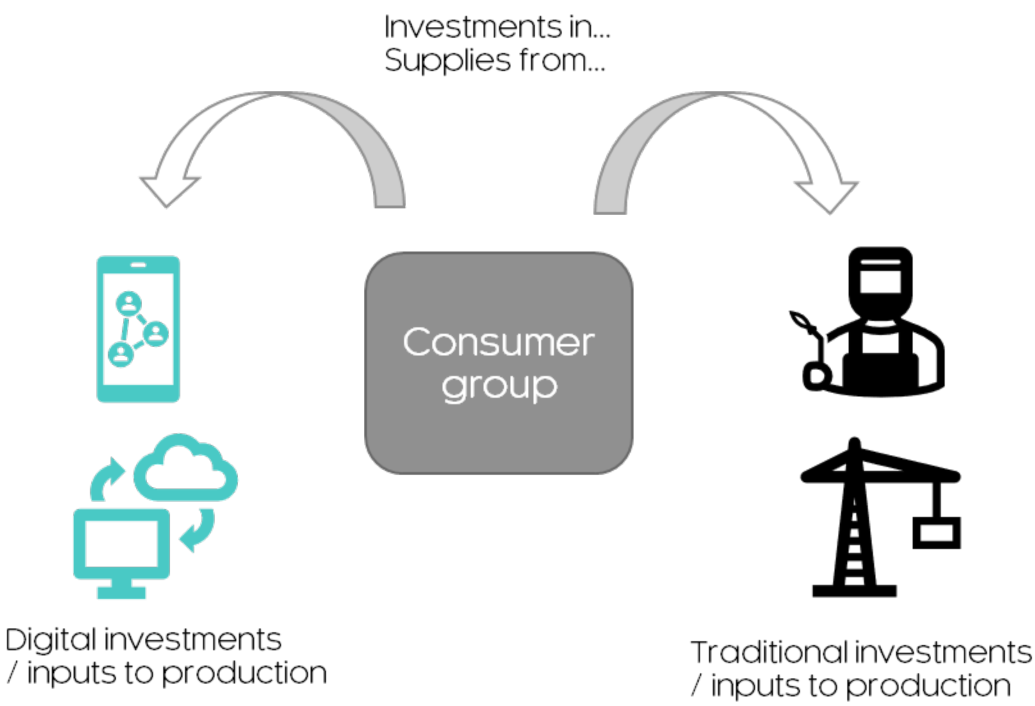
Digital intensity

The results presented thus far estimate economic benefits based on the adoption trajectories and addressable markets of the respective consumer groups and the sensitivity of the whole UK economy to 5G (based on collated evidence).

It is possible to construct an alternative measure of 5G benefits, which accounts for additional asymmetries in impact potential of consumer groups based on each consumer group's relationship with digital technology. Specifically, this approach characterises each consumer group's relationship with existing digital inputs to production and investments, by calculating the relative importance of digital technologies (in value terms) relative to traditional inputs to production and investments. The logic behind this approach is that consumer groups with more intensive use of digital inputs and assets are more likely to benefit from improvements to telecommunications technology, such as 5G. Similar approaches have been taken in the literature whereby economy-wide impacts were disaggregated by sector based on the use of ICT and communications technologies as inputs to production by each sector.

This measure does not affect the aggregate potential economic impacts from adoption in our model, but would affect the share of economic benefits experienced by each consumer group.

Figure 8-10. Illustration of digital intensity



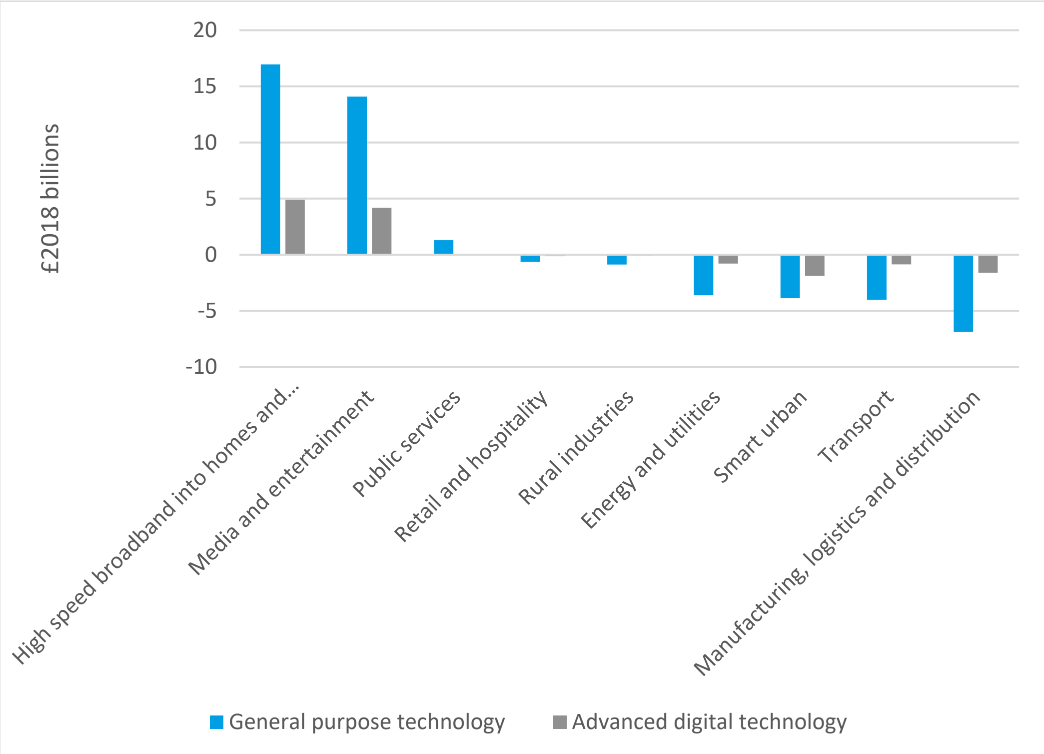
Sources: Cambridge Econometrics illustration

Economic benefits in High speed broadband in homes and offices and Media and entertainment are twice as high when weighted by digital intensity

Figure 8-11shows the change in cumulative economic benefits that would be seen in the results if consumer group impacts were weighted by digital intensity. Unsurprisingly, High speed broadband in homes and offices and Media and Entertainment both register considerably higher economic benefits under the alternative measure (+£17bn and +£14bn, respectively under the GPT scenario). This means that cumulative economic benefits are twice as high, when weighted by digital intensity.

Manufacturing, logistics and distribution and Transport, however, both register lower impacts under the alternative measure (-£7bn and £4bn, respectively under the GPT scenario). This is due to the importance of traditional investments (e.g. premises and machinery) and inputs to production (e.g. physical components) to economic activities – implying lower relative importance of digital investments/inputs to production.

Figure 8-11. Difference in GVA levels impact over baseline from weighting consumer group impact potential by digital intensity (difference between low market barrier case and central market barrier case, cumulative, 2021-35)



Sources: Cambridge Econometrics calculations, Analysys Mason Calculations, MDM-E3 econometric model, ONS Supply and Use Tables.

These results provide a helpful indication of how differences in marginal benefits of adoption across consumer groups might affect the projected impacts of 5G. The results are however based on an imperfect (albeit helpful) proxy. It is possible, for instance, that some subsectors of the UK economy which currently rely heavily on traditional inputs to production will benefit disproportionately from 5G due to fundamental differences between 5G applications and existing digital technologies.

Sub-national impacts

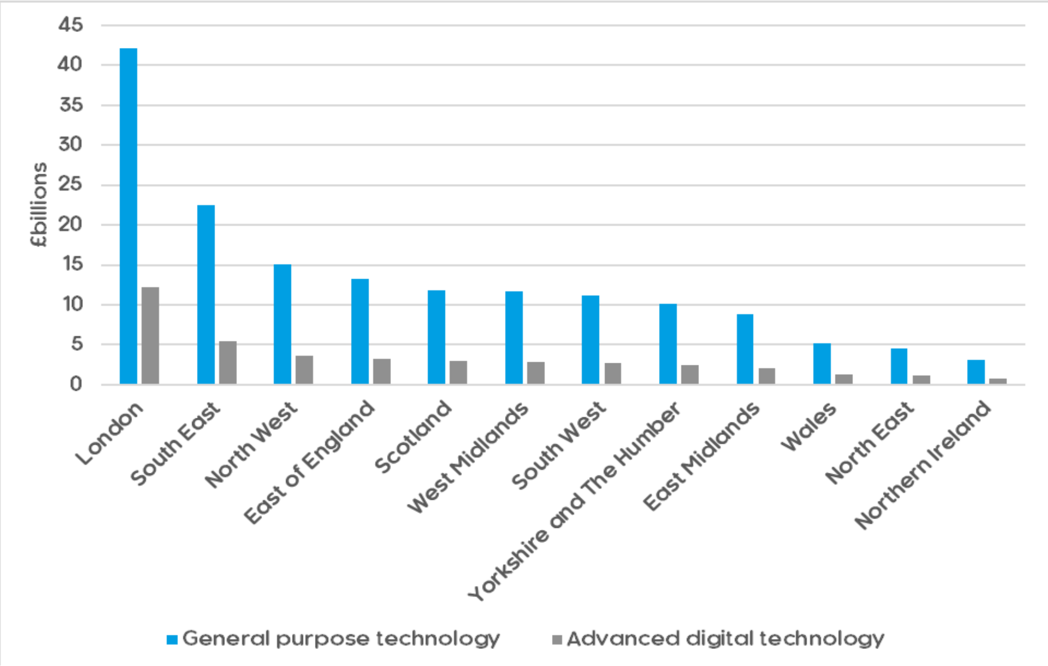
This section presents the model results for the nine English regions, Scotland, Wales and Northern Ireland, together with the impacts in urban and rural areas, both UK wide and in each region and country. In general, the absolute magnitudes of the projected impact in each UK geography is largely driven by the size of the given geography's economy. Relative impacts (measured in terms of the % difference from the baseline) are determined by several factors, most notably sub-national roll-out and the consumer group composition of each area.

5G adoption will have the greatest impact on London in terms of £s of GVA

In the general-purpose technology scenario, where adoption is widespread across consumer groups and firm sizes, the cumulative economic impact of 5G adoption over 2021-35 under the central market barriers case is projected at £42bn for London, £23bn for the South East and £15bn for the Northwest. In the advanced digital technology scenario, the size of the impacts are around four times smaller, consistent with the model assumptions and the wider literature they are based on.

Figure 8-12 below compares the projected cumulative GVA impacts over 2021-35 in each region and country in the GPT and ADT scenarios.

Figure 8-12: Cumulative GVA impacts of 5G adoption by region and country (central market barriers case), 2021-35



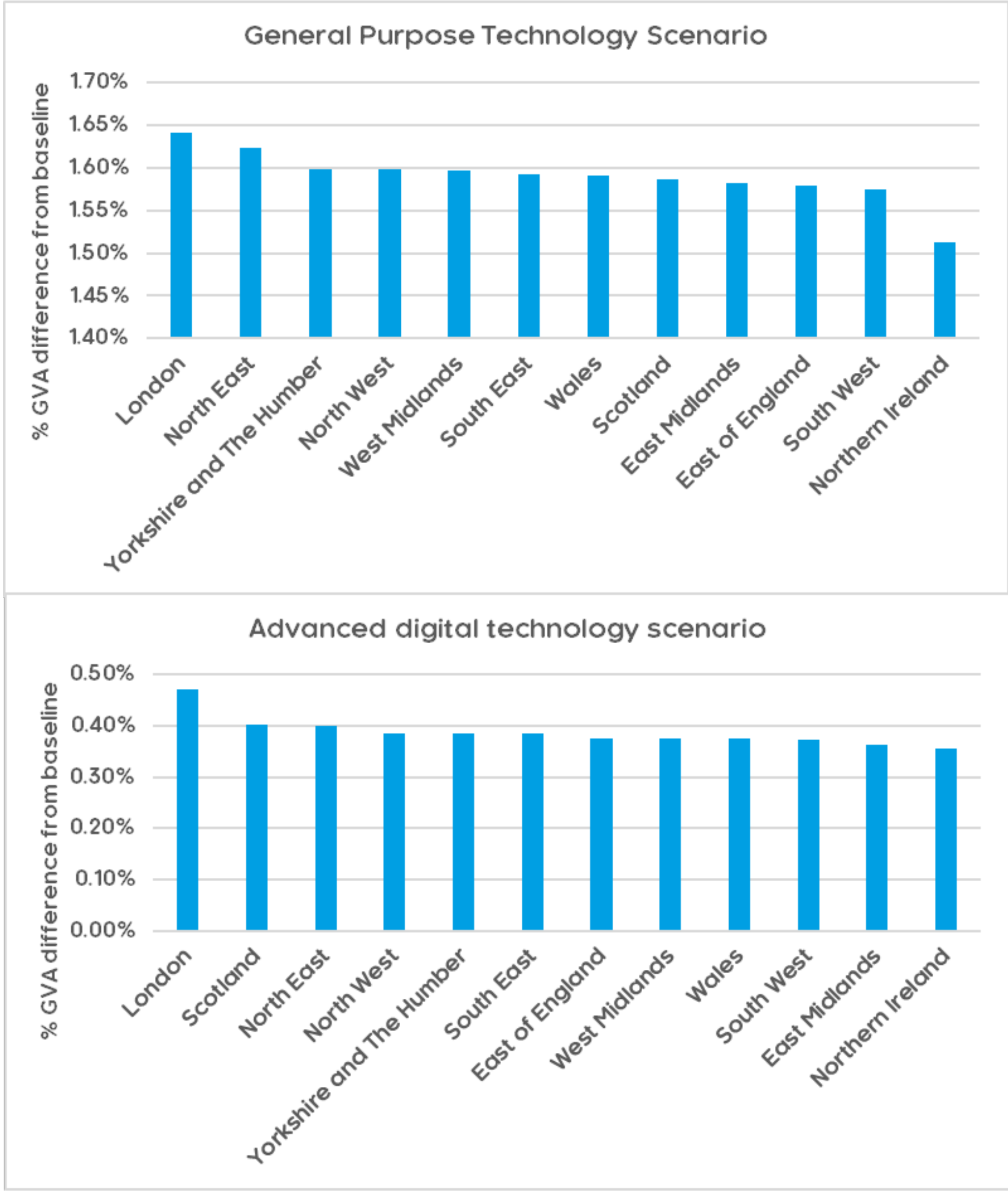
Source: Modelling by Cambridge Econometrics and Analysys Mason.

5G adoption will positively impact GVA in all UK regions and countries.

There is variation in the size of the projected impacts between each region and country, but this is not as pronounced as the variation in consumer group impacts – indicating that within each region and country there is a sizeable proportion of firms in consumer groups that could benefit strongly from 5G adoption. For policymakers, these results emphasise the value of supporting 5G adoption across each of the UK regions, Wales, Scotland and Northern Ireland.

Figure 8-13 charts the projected difference in GVA in 2035 from the no-5G baseline for UK regions and countries in the GPT and ADT scenarios under the central market barriers case. In the GPT scenario, impacts range from 1.64% in London to 1.51% in Northern Ireland, while in the ADT scenario impacts range from 0.47% in London to 0.35% in Northern Ireland. Variation between sub-national impacts is driven by variation in adoption, but on the whole, in both scenarios there is low variance in impact between regions and countries.

Figure 8-13: Impact of 5G adoption on GVA in 2035 by region and country (% difference from baseline), central market barrier case

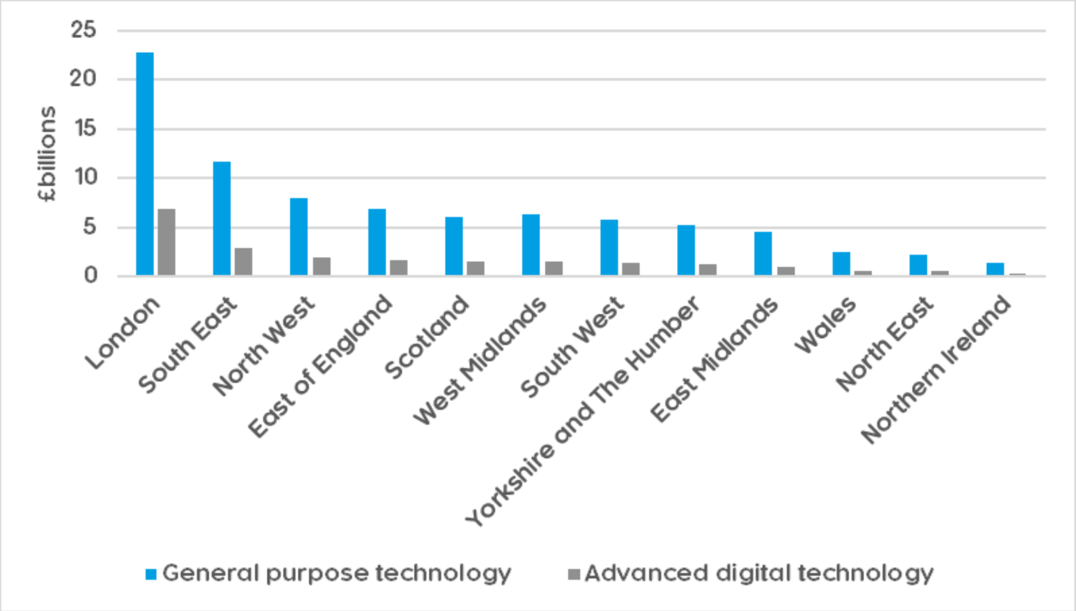


Source: Modelling by Cambridge Econometrics and Analysys Mason.

Removing market barriers would have the largest impact in the largest regions and countries

By running the GPT and ADT scenarios under the low case market barrier assumptions we can see which regions and countries stand to gain more from the removal of market barriers. In absolute terms, the gains from removing market barriers are again driven by the sizes of the regions and countries themselves. This is presented in Figure 8-14 below for the GPT and ADT scenarios, in which the largest gains from removing market barriers are projected in London (£7-23bn), the South East (£3-12bn) and the North West (£2-8bn).

Figure 8-14: Cumulative impact of removing market barriers in each region and country in the GPT and ADT scenarios over 2021-35 (difference between central market barrier case and low market barrier case)

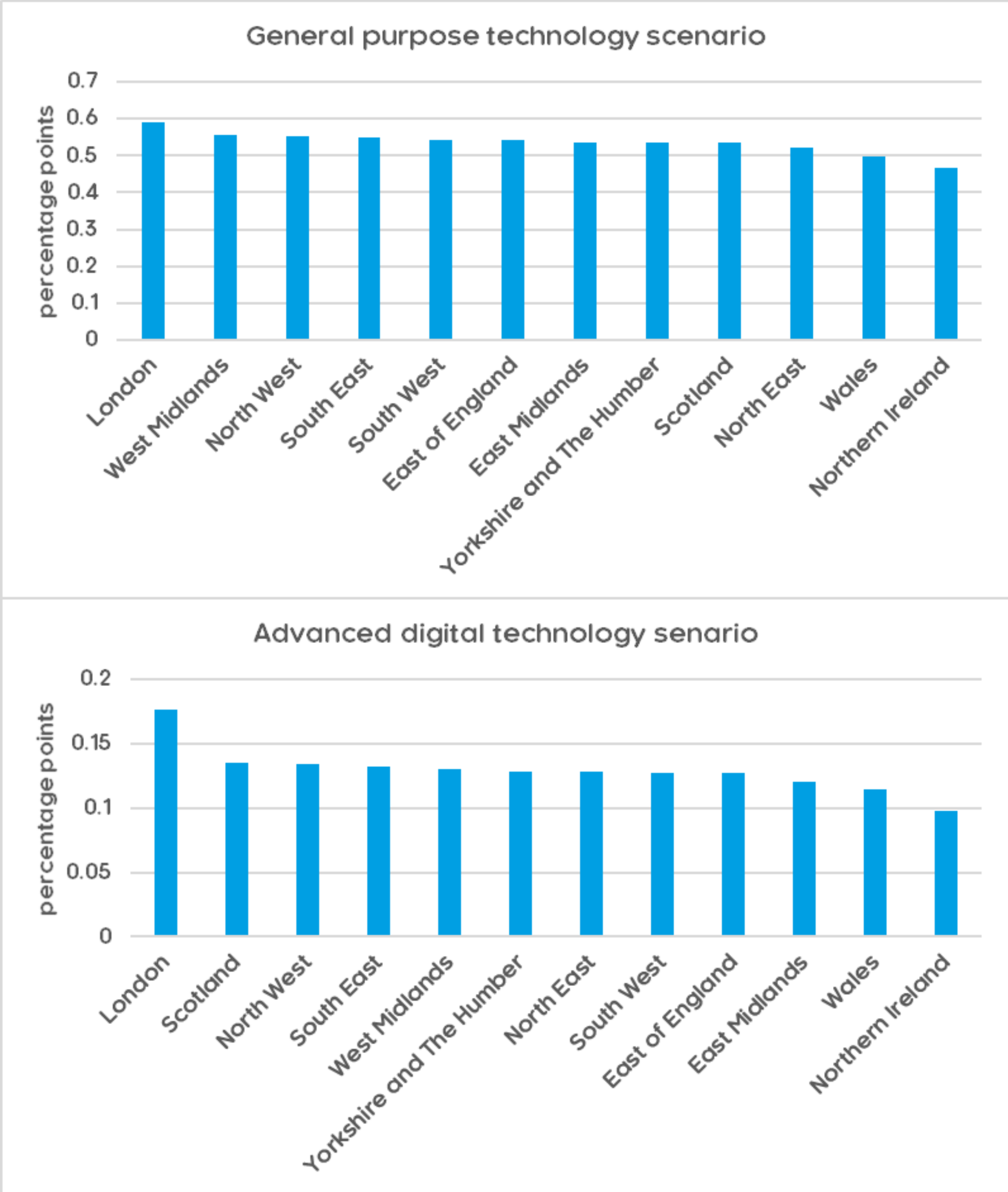


Source: Modelling by Cambridge Econometrics and Analysys Mason.

Each region and country can realize similar relative gains from the removal of market barriers

On the other hand, each UK region and country has the potential to realize similar GVA gains from removing market barriers relative to the sizes of the regions' economies. Figure 8-15 below compares the relative gains from removing market barriers in each region and country, measured as additional percentage point GVA impact over baseline in 2035. However, regions and countries with higher projected relative impacts in the central case still have slightly more to gain in the low market barriers case. For example, London, the region or country with the highest projected impact in the central case also has the most to gain from the removal of market barriers (0.18-0.59pp), while Northern Ireland, the region or country with the lowest projected impact in the central case, also has the least to gain from the removal of market barriers (0.10-0.47pp).

Figure 8-15: Additional percentage point GVA impact over baseline in 2035 from removing 5G market barriers in each region and country (difference between low market barrier case and central market barrier case)

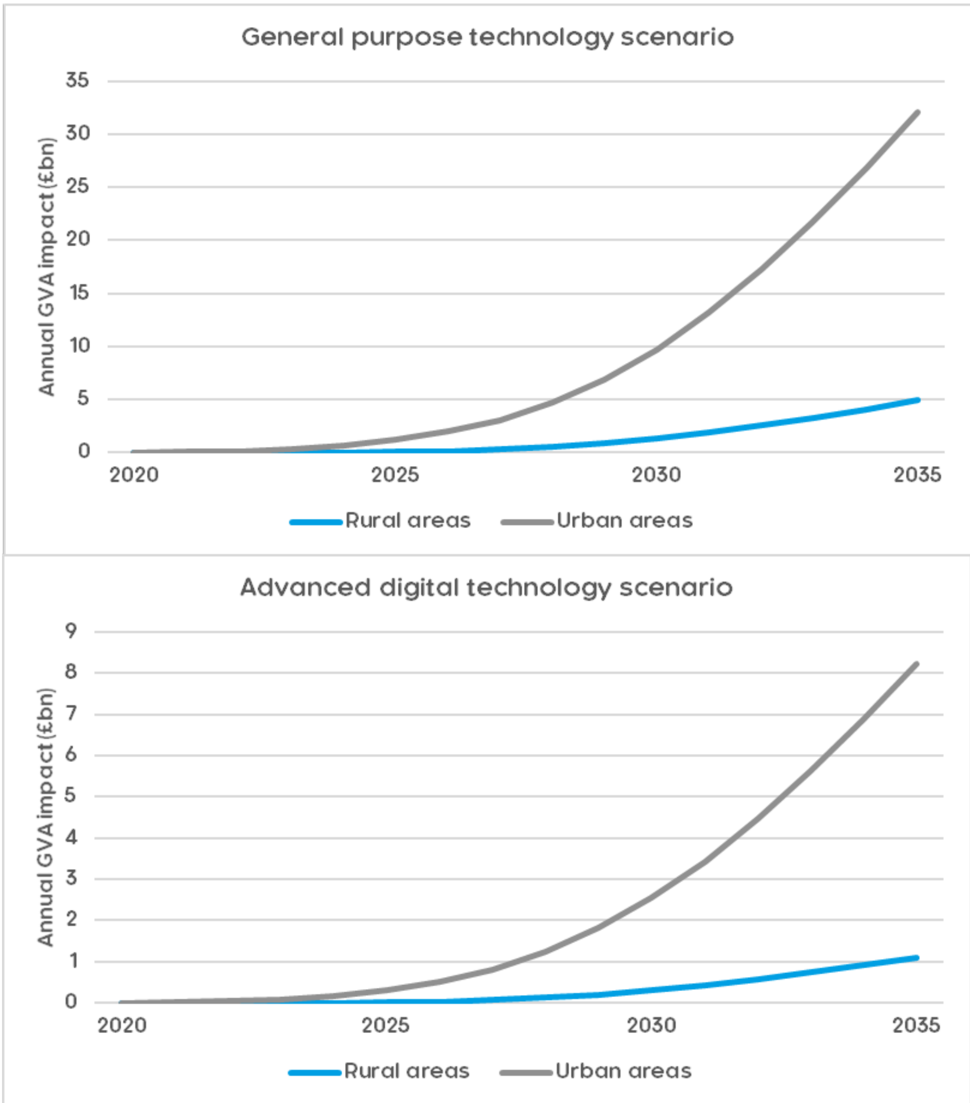


Source: Modelling by Cambridge Econometrics and Analysys Mason.

In levels terms, the impact on urban areas will be greater than rural areas

Turning to urban and rural impacts, Figure 8-16 plots the projected annual GVA impact of 5G adoption on the UK's urban areas and rural areas. Again, these impacts are mainly driven by the size of the respective economies in urban and rural areas, and hence the projected urban impacts are markedly larger, with a cumulative impact of £139.8bn over 2021-35 in urban areas compared to £19.7bn in rural areas in the GPT scenario and £36.2bn in urban areas compared to £4.5bn in rural areas in the ADT scenario.

Figure 8-16: Projected annual GVA impacts of 5G adoption in UK-wide urban and rural areas in the GPT and APT scenarios, central market barrier case



Source: Modelling by Cambridge Econometrics and Analysys Mason.

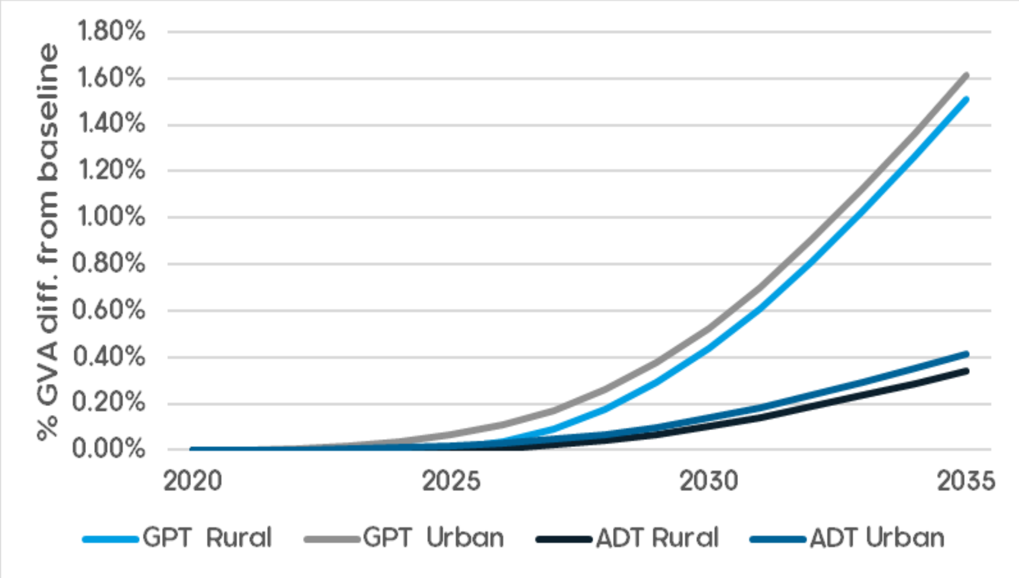
Greater urban impacts are partly driven by faster 5G roll-out and adoption in urban areas

In addition to the size of urban economies, projected greater impacts in urban areas are also driven by faster roll-out in these areas, which leads to faster adoption in urban areas. Figure 8-17 plots the projected % GVA impact over the baseline in each year across all rural and urban areas in the UK in the GPT and ADT scenarios. Impacts in rural areas are relatively smaller because roll-out, and hence adoption, does not pick up in rural areas until 2025 – this is visible on the figure below in which impacts in rural areas are negligible before 2025.

The gap between urban and rural impacts is relatively smaller in the GPT scenario

Another interesting finding shown in Figure 8-17 is that the gap between urban and rural impacts is relatively smaller in the GTP scenario. In the GPT scenario, the relative GVA impact of 5G adoption in 2035 is around 7% for urban areas than rural areas, while in the ADT scenario this figure stands at 21%. This reflects the fact that in the ADT scenario, the consumer groups with greater adoption are more concentrated in urban areas, while in the GPT scenario adoption is widespread across all consumer groups, and hence more equal in urban and rural areas.

Figure 8-17: Percentage GVA difference from baseline in UK-wide rural and urban areas over 2021-35, central market barrier case

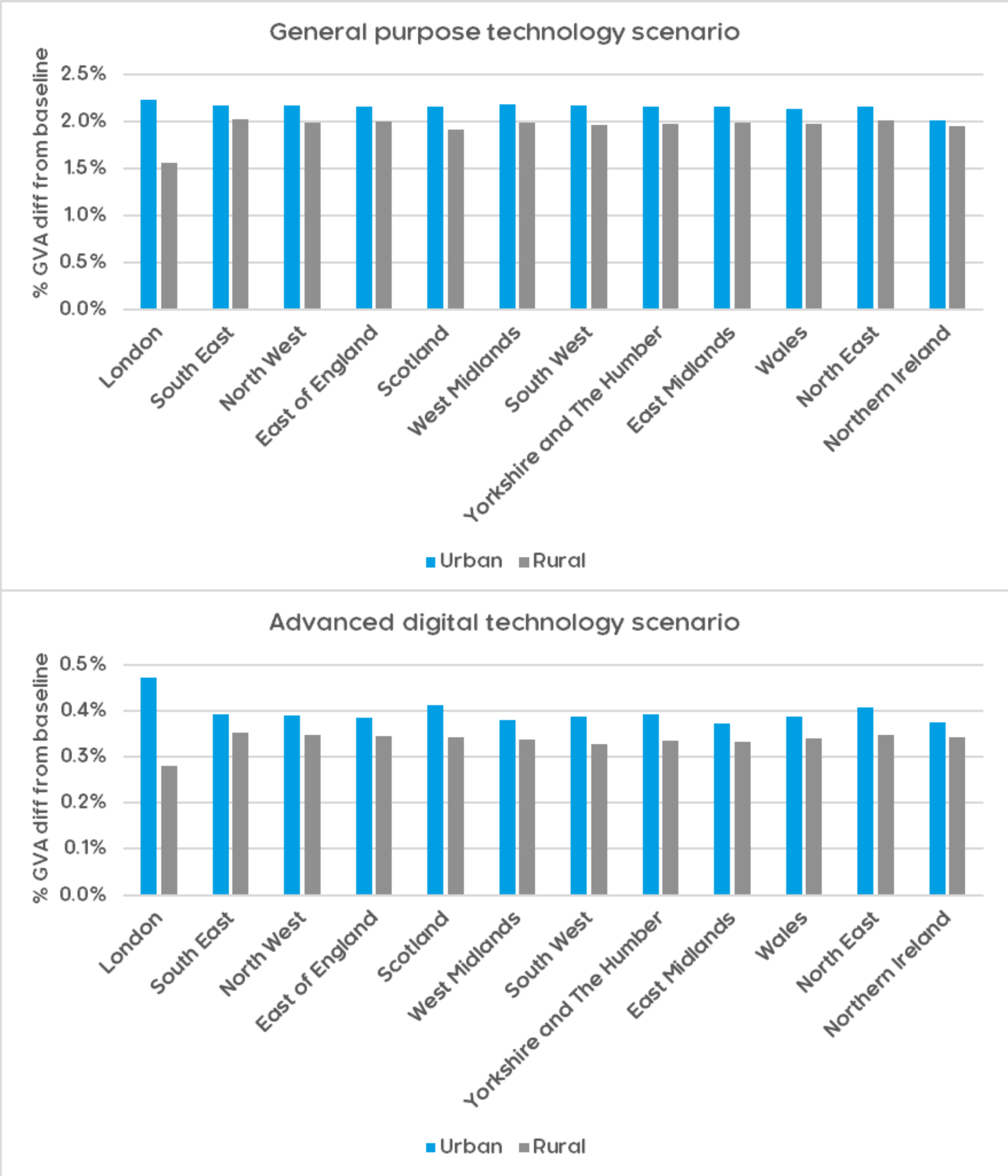


Source: Modelling by Cambridge Econometrics and Analysys Mason.

Relative urban impacts are slightly larger than rural impacts in all regions

Relative urban impacts within regions are also generally larger than rural impacts, though only by a small margin. Figure 8-18 shows the projected impacts in the urban and rural parts of each region, measured by difference from baseline GVA in 2035. Except for London, the differences between rural and urban impacts between each region are very similar, indicating similar levels of adoption in rural areas and urban areas between regions. The difference between impacts in rural and urban London stems from the composition of consumer groups in rural London, in particular relatively high importance of Public services in the local economy. However, it should be noted that rural London is a very small region.

Figure 8-18: Impact of 5G adoption on GVA (% difference from baseline) in 2035 in rural and urban areas, central market barrier case



Source: Modelling by Cambridge Econometrics and Analysys Mason.

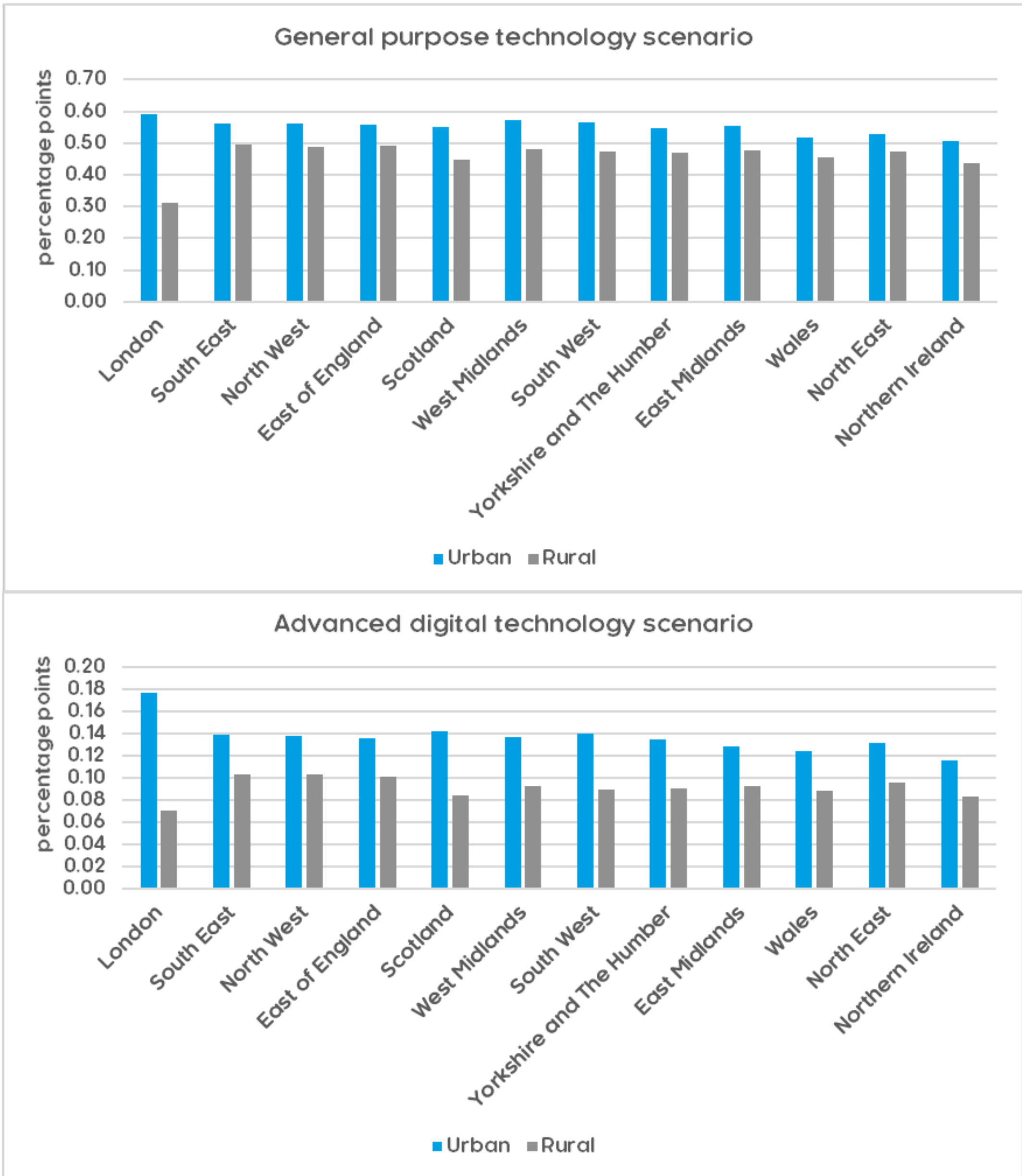
Urban areas have more to gain from removing market barriers than rural areas

Figure 8-19 shows the projected impact of removing market barriers in 2035 on rural and urban areas within regions, calculated by subtracting impacts under the central market barrier case from impacts under the low market barrier case. The main finding is that urban areas have more to gain than rural areas from the removal of market barriers, though in most cases the additional gain is only around one percentage point. This follows from the fact that adoption is low in rural areas in the earlier years under both sets of market barrier assumptions, meaning that rural areas are unable to capitalise on lower market barriers in these years. It is worth noting that if roll-out was sped up in rural areas, thus addressing a supply-side market barrier (this model only considers demand-side barriers), the gap would close somewhat between potential gains from removing demand-side barriers in urban and rural areas.

In the ADT scenario, rural areas have markedly less to gain from removal of market barriers

In the ADT scenario, adoption is modelled as lower in smaller businesses and in some consumer groups (including rural industries) compared to the GPT scenario, in which adoption is widespread across firm sizes and consumer groups. The model results show that under this scenario, the potential GVA gains for rural from removing market barriers are relatively low in the ADT scenario, at around 25-40% of the GVA gains in urban areas in 2035 compared to 10-18% in the GPT scenario[40].

Figure 8-19: Additional percentage point GVA impact over baseline in 2035 from removing 5G market barriers in within-region/country rural and urban areas (difference between low market barrier case and central market barrier case)



Source: Modelling by Cambridge Econometrics and Analysys Mason.

[40] This excludes London, which has a very small rural area and for which rural results should be treated as an outlier.

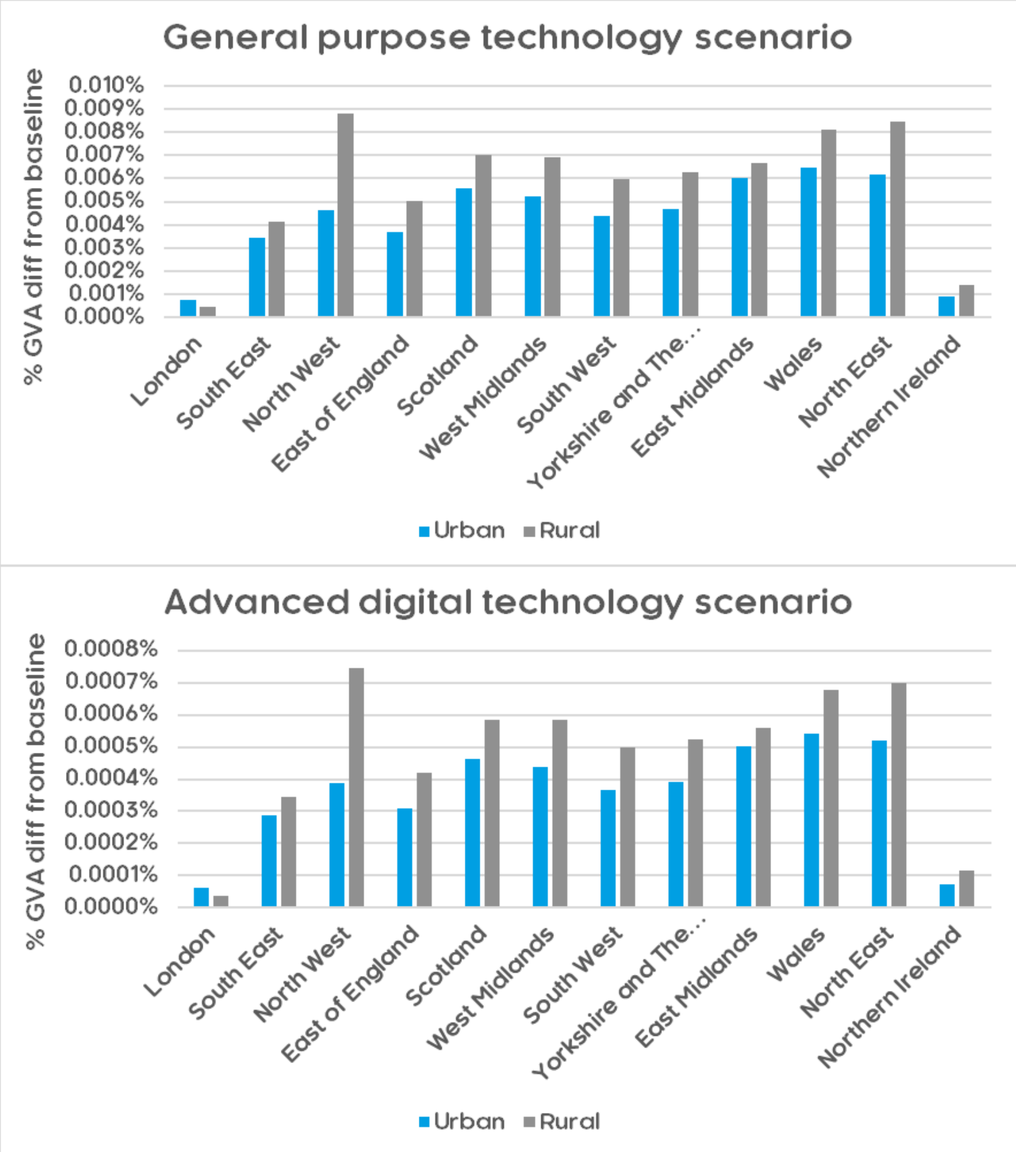
There is limited evidence around the future extent and profile of private network use

Given that private networks are a new feature of mobile networks and that very few firms have adopted private networks (or 5G in general) at the time of writing, there is great uncertainty around the extent to which private networks will be adopted and the types of firms which will use private networks. The impact model includes the option for the model user to explore the potential impacts of private network adoption by different consumer groups on the regional GVA, but it is important to stress that we are not forecasting private network adoption in this report.

Private network adoption could have greater impacts in rural areas

Nonetheless, it is still interesting to consider the potential impacts of private network adoption based on the current profile of private network adoption in the UK. Figure 8-20 below projects relative impacts of private network adoption on UK regions and countries, based on the assumption that only the largest firms in the manufacturing, logistics and distribution consumer group and the energy and utilities consumer group will use private networks (and only 5% of adoption in these consumer groups will use private networks). While the impacts are very small (directly because adoption is assumed to be small), the model results are interesting in that rural areas are projected to see greater private network adoption and impacts than urban areas. This reflects a relatively high concentration in rural areas of firms in the manufacturing, logistics and distribution consumer group and the energy and utilities consumer group.

Figure 8-20: Projected impact of 5G adoption using private networks on region/country GVA (% difference from baseline) in 2035 in rural and urban areas, central market barrier case



Source: Modelling by Cambridge Econometrics and Analysys Mason.

8.3 Environmental impacts

This section present projections of environmental impacts from the model in terms of avoided CO2 emissions and monetised using BEIS carbon price projections. Note that our approach to modelling each type of impact was shaped by the available evidence, and as such we have had to use separate methodologies from the economic impact estimates. This means that the monetised social and environmental impact estimates should not be added to the economic impact estimates.

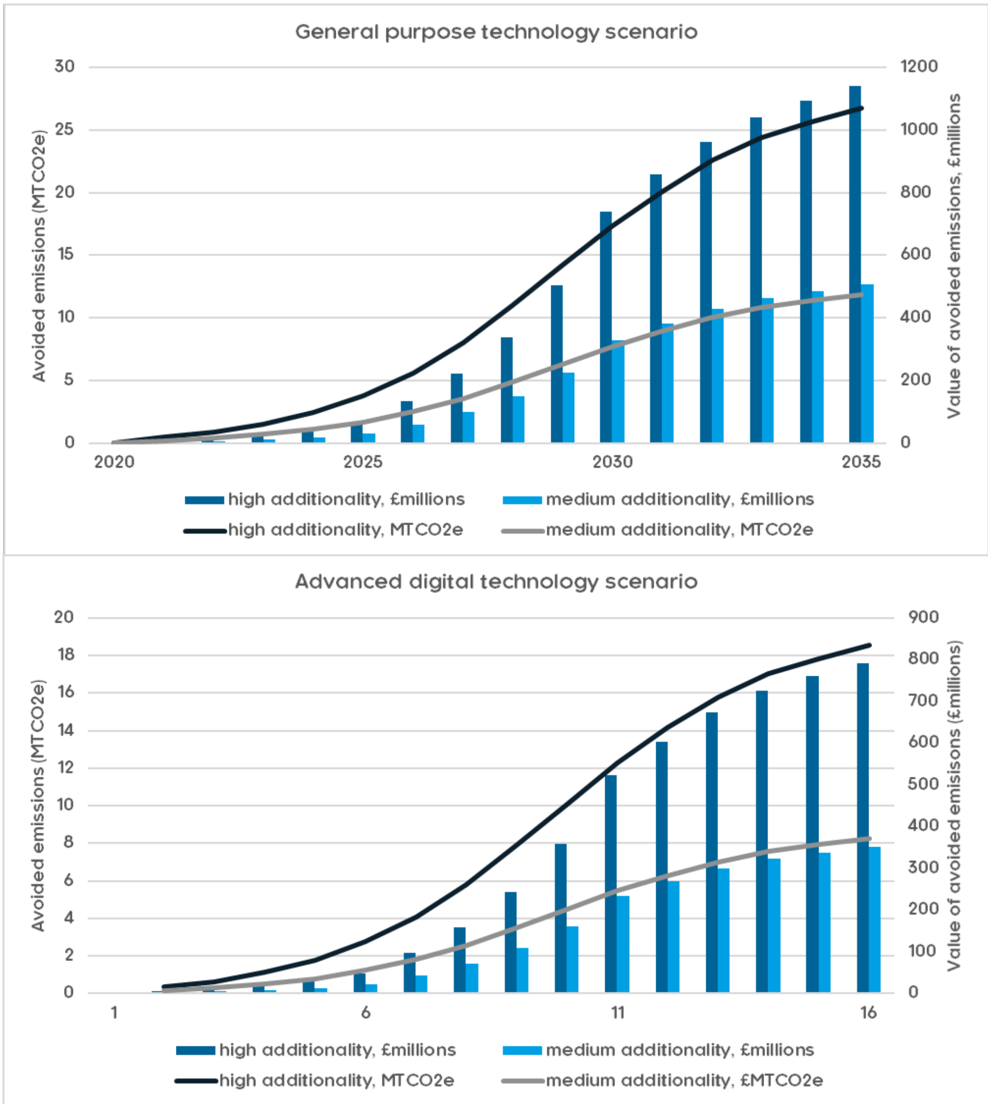
The estimated impacts measure the impacts in terms of avoided emissions attributable to 5G-enabled features of certain mobile technology use cases. These estimates concern only the incremental emissions savings over the emissions savings offered by the present-day mobile technologies. Before discussing the results, it is worth noting that the environmental impacts may be greater if new 5G use cases emerge in future with the ability to facilitate further emissions savings. The projections in this model are based on current use cases for mobile network technology which are hence most likely a sub-set of the future use cases through which 5G could lead to lower emissions. This means that the GPT scenario projections should be viewed as lower bounds; 5G as a GPT technology would have a much wider set of use cases than 4G, but we do not yet have empirical data on the potential for these use cases to lower emissions.

Up to 184 million tonnes of CO2 could be saved due to 5G adoption over 2021-35

The model results show increasing annual emissions savings from 5G adoption over 2021-35. In the most ambitious scenario, where 5G is modelled as a GPT technology, annual avoided emissions reaches around 27 million tonnes of carbon dioxide equivalent (mtCO2e) by 2035, and cumulative avoided emisisons over 2021-35 equal around 184mtCO2e. The path of these emissions savings is projected to follow the path of adoption, with annual emissions savings growing each year as adoption increases.

Figure 8-21 shows the projected avoided emissions in the GPT and ADT scenarios, together with their estimated monetary value. The GPT impacts are markedly larger in the ADT case, driven by wider adoption of the modelled use cases, though as noted above we would expect the gap between the two scenarios to be even larger after accounting for future GPT use cases for 5G (for which data is currently unavailable).

Figure 8-21: Projected annual avoided emissions from 5G adoption over 2021-35 in the GPT and ADT scenarios, central market barriers case



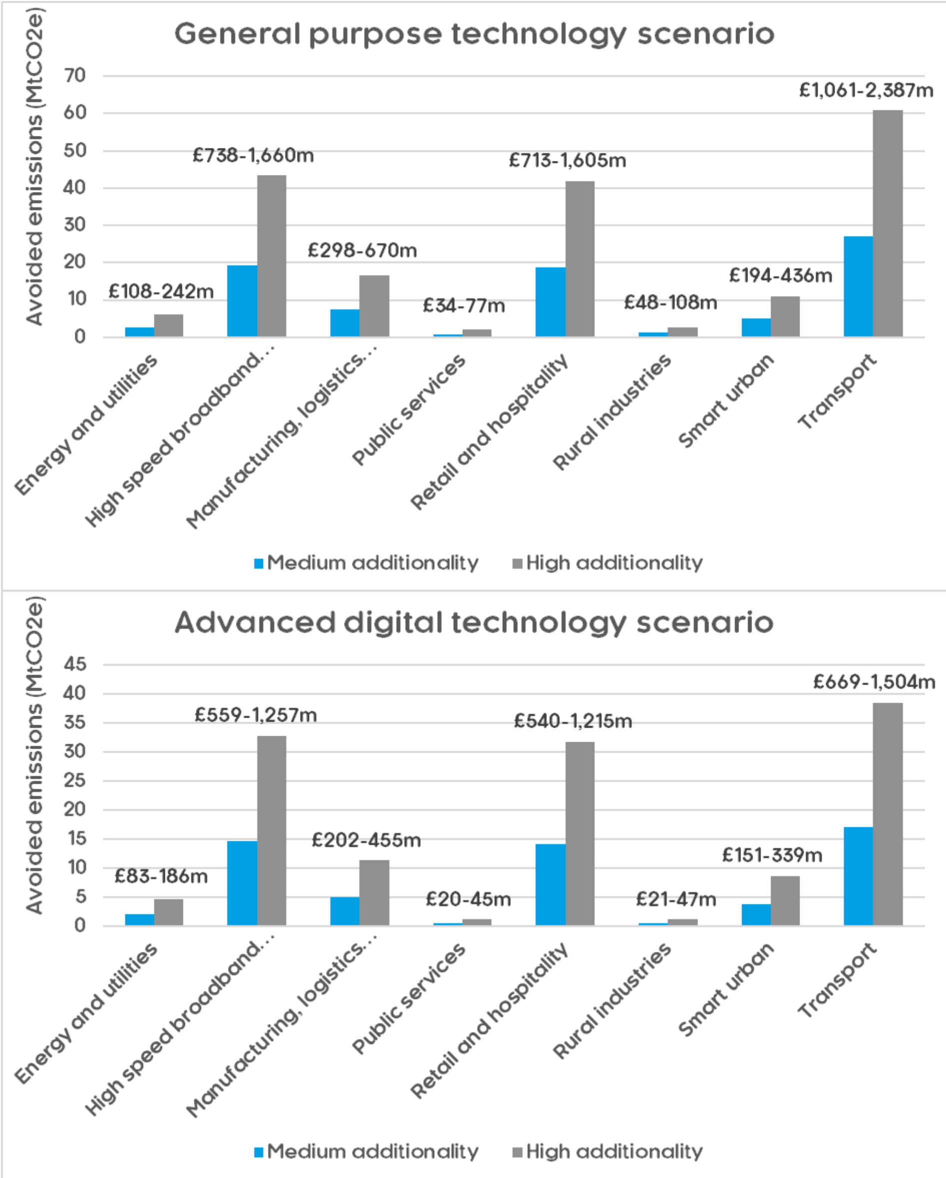
Source: Modelling by Cambridge Econometrics and Analysys Mason.

Avoided emissions are greatest in consumer groups for which 5G improves transport efficiency or reduces travel

The projected emissions savings for each consumer group[41], together with monetised value of these savings, are presented in Figure 8-22 below for the modelled scenarios. The greatest emissions savings are projected to result from 5G adoption of use cases in the transport, high speed broadband into offices and homes and retail and hospitality consumer groups. This is because many of the modelled use cases classified within these consumer groups lead to improved transport efficiency or reduced travel (and hence lower transport vehicle emissions). These types of use cases were found to bring particularly high enabled emissions savings in (GSMA 2018). Examples of such use cases include smart logistics and traffic congestion management (transport consumer group), smart working use cases (high speed broadband into offices and home consumer group), and mobile shopping applications (retail and hospitality consumer group).

[41] Note that we have not estimated environmental benefits for the media and entertainment consumer group as none of the avoided emissions factors from (GSMA 2018) correspond to the media and entertainment use cases.

Figure 8-22: Projected cumulative avoided emissions from 5G adoption over 2021-35 in each consumer group, central market barriers case



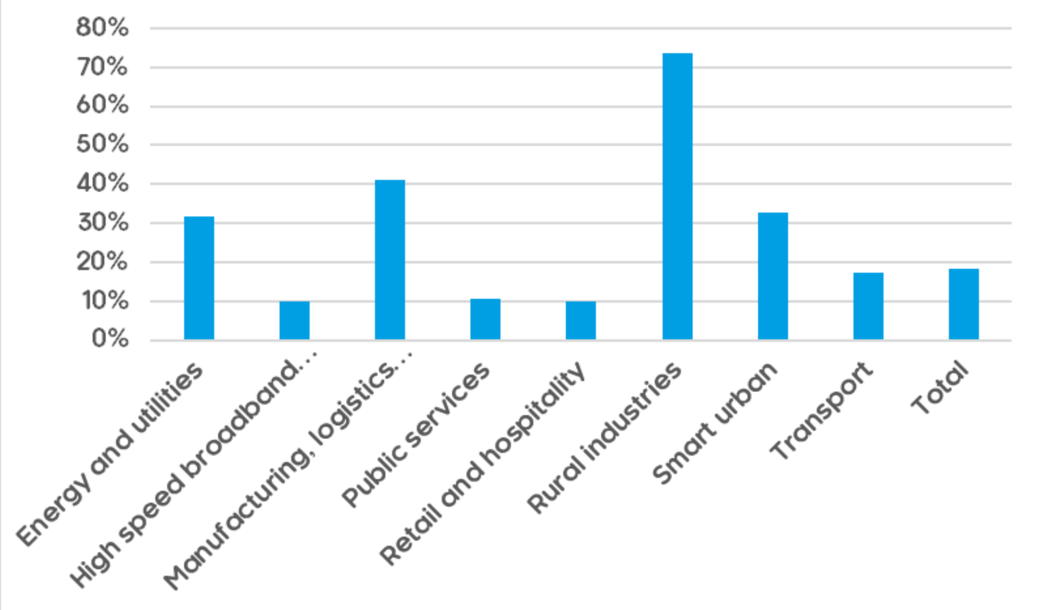
Source: Modelling by Cambridge Econometrics and Analysys Mason.

Potential emissions savings from removing market barriers are highest in rural industries, manufacturing, logistics and distribution, smart urban and energy and utilities

After running the model with low market barrier assumptions, the results indicate that total cumulative emissions savings over 2021-35 would increase by around 18% if market barriers were removed. However, the potential savings are much larger for some consumer groups than others. Consumer groups for which business use cases were modelled are projected to realise relatively higher emissions savings as a result of removing market barriers, with the highest potential savings in rural industries (73%), manufacturing, logistics and distribution (41%), smart urban (33%) and energy and utilities (32%). In these consumer groups, emissions saving 5G use cases are mainly business use cases whereas in the other consumer groups, the modelled use cases are largely 5G consumer smartphone applications, which have been modelled as having lower market barriers in the central case.

Figure 8-23 below shows the percentage increase in cumulative emissions savings in each consumer group and in total from removing market barriers.

Figure 8-23: Percentage increase in avoided emissions in each consumer group and in total from removing market barriers, (calculated by comparing the central market barriers case to the low market barriers case)



Source: Modelling by Cambridge Econometrics and Analysys Mason.

Note: that these percentages do not differ between the GPT and ADT scenarios because the impact market barriers unchanged between the two scenarios

8.4 Social impacts

Social impacts are estimated as the time savings resulting from consumer IoT devices with features supported by 5G features that result in time savings for individuals. These time savings have been converted to monetary values of time saved using the approach described in Section 6.6 (the social impact estimates should not be added to the economic impact estimates – see Section 8.2).

The estimates are subject to a substantial degree of uncertainty

It is worth noting that the estimated impacts are based on the lower-end parameters obtained from the reviewed literature. Use of higher-end parameters in model calculations could result in estimates that are over twice as high. Therefore, a high degree of uncertainty remains over the estimated time savings and their value. At the same time, the remaining social benefits of 5G which could not have been quantified due to lack of data (health, wellbeing, quality of life etc.) could also be significant, and their potential value should be considered when assessing uncertainty of the estimated social benefits.

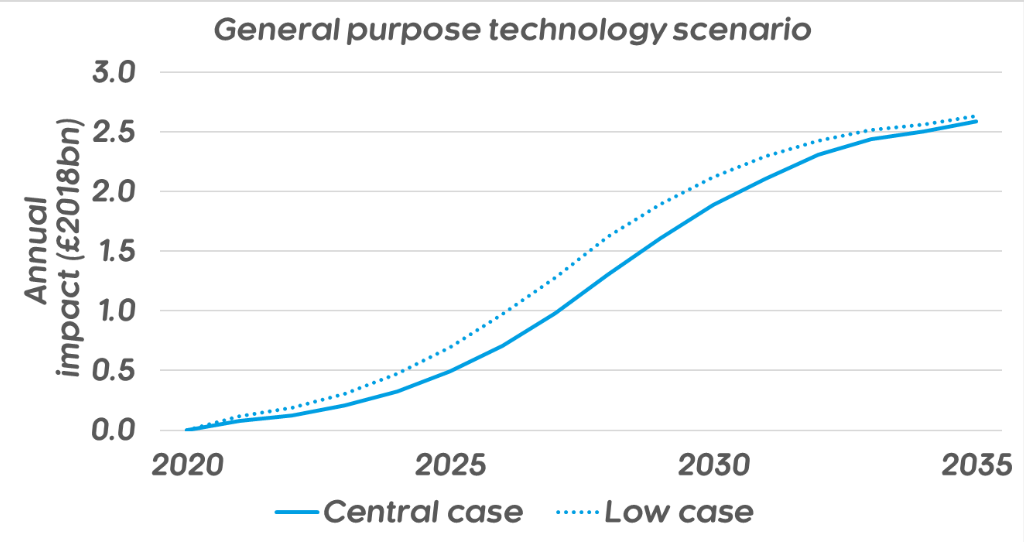
Figure 8-24 presents the evolution of annual value of total time saved under the GPT scenario, for both central and low market barrier scenario cases. Adoption of 5G-enabled IoT consumer technologies is assumed to follow the same pattern as adoption of ‘High-speed broadband into homes and offices’. The projected market penetration is also assumed to be the same as for businesses under the respective addressable market assumptions for ‘High-speed broadband into homes and offices’ consumer group under the GPT or the ADT scenario assumptions. Therefore, the gradual increases in annual value of time saved follow a similar pattern. Annual value of time saved is projected to reach £0.5bn in 2025 under the central barriers case, or £0.7bn under the low barriers case.

Under the GPT scenario assumptions, the annual value of time saved is projected to reach £2.6bn in 2035

Due to the increasing adoption of 5G-enabled household and personal IoT devices, by 2030 the annual value of time saved will reach £1.9bn under the central barriers case, or £2.1bn under the low market barrier case. In later years adoption converges under the central and the low market barrier cases, resulting in similar estimated values of time saved reaching, at £2.6bn annually under both scenarios in 2035.

The annual value of time saved curve has a different shape to that of the economic benefits curves presented in Figure 8-6. This is because in the calculation of economic benefits, adoption affects the GVA growth rate each year, which compounds over the years to produce a difference from the baseline, and a difference between the Central and the Low barrier scenario cases. In contrast, calculation of social benefits assumes that adoption determines the level social benefits in any given year, which are not influenced by the previous years' adoption rate.

Figure 8-24: Value of time saved under GPT scenario – Central and Low market barrier cases.



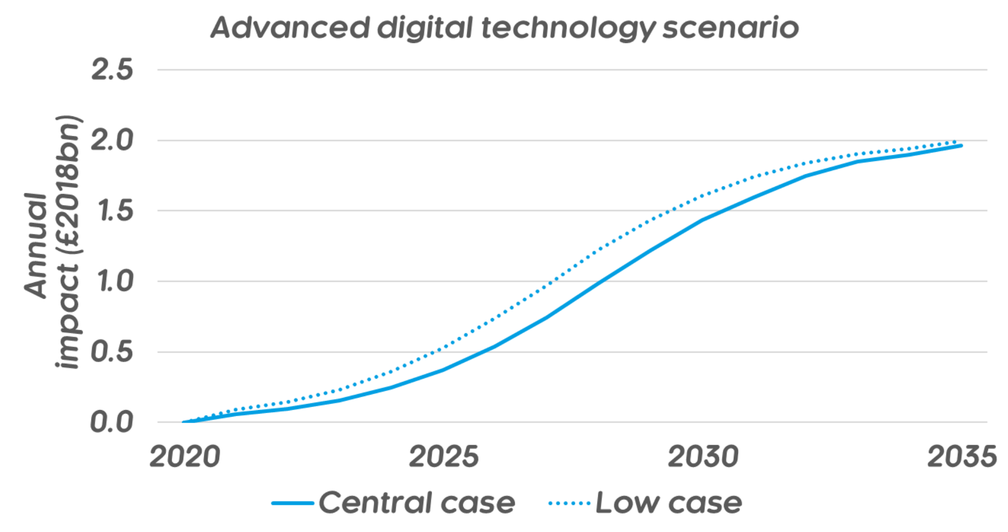
Source: Modelling by Cambridge Econometrics and Analysys Mason.

… while under the ADT scenario assumptions, the annual value of time saved is projected to reach £2.0bn in 2035

Analogous results are presented in Figure 8-25 for the ADT scenario, for both central and low cases of market barriers. As adoption rate of 5G-enabled IoT devices by individuals is assessed to be lower than in the GPT scenario, the monetary value of time saved is also lower.

The annual value of time saved (UK-wide aggregate) in 2020 reaches £0.4bn under the central barrier case, and £0.5bn under the low barrier case. In 2030, these values increase to £1.4bn and £1.6bn under the central and low barrier assumptions, respectively. In 2035 the difference between the two barrier scenarios declines, with annual value of time saved increasing to £2.0bn under both scenarios.

Figure 8-25: Value of time saved under ADT scenario – Central and Low market barrier cases.



Source: Modelling by Cambridge Econometrics and Analysys Mason.

Cumulatively over 2020-35, removal of market barriers could result in time savings worth £2.5bn under the GPT scenario or £1.8bn under the ADT scenario

Comparisons of cumulative impacts over the modelled period (2021-35) demonstrate the potential impact of removing market barriers. Under the GPT scenario assumptions, the cumulative value of social benefits is estimated at £19.7bn for the central market barriers case, and at £22.1bn for the low market barriers case. This means that removal of market barriers could result in an additional £2.4bn of social benefits under the GPT scenario assumptions over the 2021-35 period.

Under the ADT scenario assumptions, the cumulative value of social benefits is estimated at £14.9bn for the central market barriers case, and at £16.7bn for the low market barriers case. Therefore, removal of market barriers under the ADT scenario assumptions could result in an additional £1.8bn of social benefits over the 2021-35 period.

8.5 Benchmarking the model results

One way of assessing the uncertainty around the model results and to get a feel for the plausibility of the results is to benchmark against other studies. This allows a feel for how conservative or optimistic the model results are compared to other studies. Table 8-2 below compares the economic impact estimates from our model to several other studies that have also attempted to project the impact of 5G on the UK or other economies with similar characteristics.

Table 8-2: Cross-study comparison of economic impact estimates of 5G

Country	Study	Impact of 5G by 2030	Impact of 5G by 2034	Impact of 5G by 2035	Impact of 5G by 2050
UK	Cambridge Econometrics and Analysys Mason (2021)	£2.7bn - £16.3bn	£7.6bn - £35.6bn	£9.1bn - £42.0bn	-
	GSMA (2020)	£5.16bn	£12.7bn	-	-
	(PwC 2021)	£43bn	-	-	-
Scotland	Deloitte (2019)	-	-	£17bn	£34bn
Australia	Australian Government (2018)	£24.7bn	-	-	£33.5bn - £156.2bn

Source: Cited studies and Cambridge Econometrics calculations.

Two insights stand out from inspecting the results in the above table. Firstly, the projections from our model are relatively conservative compared to the wider literature. The results from the ADT scenario are markedly lower than the findings from the other studies, with the results from the GSMA study closest to the ADT scenario projections, though still almost twice as large. On the other hand, PwC estimate benefits far greater than the GPT scenario in our model, while Deloitte and the Australian Government also estimate larger impacts, after taking into account that they are estimating impacts for smaller economies than the UK.

This leads us on to the second finding from this benchmarking exercise – the wide range in the magnitude of the benefits projected by the various studies. This wide range of magnitudes is indicative of the high levels of uncertainty around the future impacts of 5G adoption, given the lack of empirical evidence, and the sensitivity of the estimates to the methodology and assumptions employed.

It is difficult to pinpoint the reasons behind the variation in magnitude of the estimates of each of these studies. Regarding the conservativeness of our estimates compared to some of the other studies, one reason is likely our focus on quantifying only additional impacts of 5G. We sought to capture additional in our study by considering historical impacts of previous technologies for sufficient data were available to empirically estimate additional impacts. On the other hand, studies that rely on stakeholder inputs or on estimates of technologies associated with 5G (but not for which 5G is critical) are less likely to have fully accounted for additionality. However, the key driver of the wide range of estimates is the lack of empirical data to ground the model in, meaning that to quantify the impacts assumptions have to be developed which require a degree of subjective judgement. It is thus important to bear in mind that much of the value of the model lies in the relative results (i.e. comparisons between consumer groups, market barriers and geographies) than the absolute results, which we have tried to bring out in our discussion of the model results.

9 Conclusions

9.1 5G use cases and consumer groups

The literature suggests a diverse range of potential 5G use cases for individuals, households and businesses.

At this stage of 5G development, many of the potential use cases have yet to reach commercial maturity. Many trials are under way into individual use cases (and clusters of use cases) that individual businesses have identified as potentially useful or necessary to their businesses and which might be enabled through 5G. Some early adopters of 5G previously used 4G connectivity, and some have and still do use Wi-Fi and other short-range wireless technologies for some of the use cases that 5G will support. Many businesses rely on fixed broadband to provide their main business connectivity. What 5G offers for businesses that have invested in existing technologies will vary depending on the nature of each business and the individual requirements that businesses have.

9.2 5G positioning relative to other connectivity technologies

5G will bring incremental benefits over 4G

It is difficult to generalise the benefits of positioning of 5G over existing technologies, since the range of potential use cases and sectors of the economy that might use 5G are so broad. Evidence from the literature we have reviewed on the incremental benefits of 5G over 4G typically refers to aspects such as the amount of data that 5G is able to transfer being considerably higher, the ability to maintain connections with very low latency, ability to deliver contextual information in real time (e.g. maps, physical objects, environments) and the ability to connect many devices, and process and utilise data from those devices, in real time.

But 5G, together with other technological advances, could also have more transformational impacts

Together with other technological advances such as industrial AR/VR applications, robotics systems and cloud computing taking place in parallel with the evolution of 5G, the 5G migration from 4G will potentially represent a more transformative change in mobile connectivity than that from 3G to 4G, for example. However, significant uncertainties exist still concerning the rate of adoption, and the scale of the benefits achieved. For this transformational benefit to be achieved, there is a need for 5G infrastructure and the associated software and hardware that 5G will integrate with (cloud-based core networks, AR/VR, robotics and the associated software delivering machine manipulation, data mining and precision processes, for example) to be deployed in full, including virtualised, cloud-native 5G core networks, end-to-end slices and wide geographic coverage and capacity.

Wi-Fi 6 could be a substitute for some, but not all 5G use cases

Although some degree of momentum exists behind developments of Wi-Fi 6 to increase capacity and functionality of Wi-Fi solutions, the eco-system for Wi-Fi remains one of a low power, short-range wireless solution, suited to specific deployment environments only. It is very likely that, in some environments and for some use cases, Wi-Fi will remain sufficient to meet the needs of some of the use cases and consumer groups considered in this study (and there may be benefits of using Wi-Fi for some uses and environments, for example if economies of scale make deployment costs favourable when compared to other options). A key question in the UK and in Europe with regards to Wi-Fi 6 is the extent to which additional spectrum in the upper 6GHz band might be available for Wi-Fi use. European countries including the UK have agreed to making the 5945-6425MHz band available for Wi-Fi (including Wi-Fi 6). In the USA, an additional 700MHz (6425-7125MHz) is being made available on a licence-exempt basis, suited to Wi-Fi use. A decision on future use of the 6425-7125MHz band in other markets, including Europe, is under study ahead of the ITU World Radiocommunications Conference, taking place in 2023. 5G proponents in Europe (including the major 5G equipment vendors) are favouring this spectrum being used for licensed 5G use.

9.3 Barriers to 5G adoption

Barriers to adoption include cross-market barriers and market-specific barriers

The study has identified several key barriers to 5G adoption which, if not addressed by the market and/or via proactive Government action, might either delay or slow adoption of 5G within some or all 5G consumer groups. Macro barriers are cross-market barriers cutting across multiple areas/consumer groups and 5G applications. These include willingness to pay for 5G services by individuals and businesses, and lack of awareness concerning suitability of 5G and/or the benefits that 5G will deliver, together with the mobile industry's uncertainty over further 5G investment within public networks ahead of demand being established. Micro barriers include multiple barriers affecting some or several consumer groups and some 5G applications e.g. eco-system barriers.

The market face a 'chicken and egg' issue

A need for short-term ROI from MNOs investing in step-by-step increments to 5G functionality in public mobile networks potentially creates a supply-side barrier that will prevent the market developing at the pace that policy makers, and some potential users, might wish. This 'chicken and egg' issue might resolve in due course e.g. rapid adoption of 5G SA devices by individual consumers might incentivise further investment in 5G SA features benefitting a range of consumer groups.

Scaling up 5G public networks could incentivise earlier adoption

A key conclusion is therefore that MNOs and 5G vendors should be encouraged to work on implementing the latest 5G features and scaling up UK 5G networks to deploy these features, such that nationwide networks will, in time, address the full range of use cases that 5G technology will support. This scaling up of 5G public networks to cater for the full range of use cases (via 5G standalone networks with slicing) might help to reduce risk to early adopters wishing to utilise these nascent 5G features.

Some users face a skills challenge with regard to 5G implementation

It is evident from literature and from evidence gathered during this study that there is substantial momentum in the 5G ecosystem. There is also significant awareness in the market on what 5G 'could' deliver. However, behind the 5G vision is a complex range of implementation issues, and some 5G users at least (especially smaller businesses) are challenged by not having the internal capability and skills needed to set up and integrate 5G connectivity into existing business systems. This skills challenge is especially relevant given the early stage of 5G implementation, given that systems are far from being commoditised (and may never be). Businesses whose core activity is not telecommunications may also not be well placed to drive the broader 5G features and evolution agenda (e.g. they do not participate in 3GPP or other 5G industry forum). Thus, there is a key role (and cost therein) for 5G solutions experts (be those the large 5G vendors, system integrators or large IT firms) to provide professional support services to smaller firms in particular with respect to 5G implementation, maintaining solutions, together with scaling up and evolving these systems as new features emerge. However, a key risk is that this ‘service support’ cost can be sizeable (representing a tangible barrier to adoption for smaller firms).

One positive implication of the momentum that exists behind the 5G ecosystem is that substantial investment continues to be made by the large equipment vendors into optimising and enhancing 5G solutions. The 5G ecosystem might also emerge to be more dynamic and flexible, compared to previous generations of mobile technology, due to the parallel developments into open software solutions and cloud-based architecture. Thus, the opportunity exists for smaller scale innovators to play a bigger role in the 5G ecosystem compared to previous generations of wireless technology.

9.4 The role of private 5G networks

Private networks are currently important to the market, but could cause fragmented demand across the UK

What is also evident from the study is that the role of private 5G networks appears to be important in the market place in the short term, at least to demonstrate proof of concept of 5G being capable of addressing specific business needs, albeit in a mode of deployment that is contained within the premises of individual businesses. This creates a risk of fragmentation, if the various deployment options for 5G (NSA, SA, public, private) do not converge to enable seamless operation across devices and domains, and across the UK. There is a specific risk that private 5G deployment might result in fragmented demand for industrial applications across the UK (e.g. if some industries can access 5G services where others cannot), which risks slow investment by MNOs to add further capabilities if demand is not evident at scale.

Funded trials and test-bed activities will remain relevant and useful

Finally, as 5G gains momentum both in private and public network deployments, another conclusion from the study is that funded trials and test-bed activities will remain relevant and useful to raise the awareness on 5G implementation and lower the barriers to deployment.

9.5 Barriers that the market will address

Some barriers will be addressed by the market

We can expect that some of the barriers that this report discusses will be addressed by the market as the 5G market evolves (e.g. achieving further roll-out of the latest 3GPP 5G features).

The two key demand-side barriers which we expect will be addressed by the market include ‘cultural resistance to change’ and ‘existing technologies are seen as sufficient’. As such as the momentum surrounding the 5G ecosystem continues to develop we expect these will be naturally addressed by the market overtime.

Whilst some barriers will be addressed as the 5G market evolves, there are several key barriers which the market might be slow to address, or which the market may not address at all absent of targeted Government policy. These are discussed in the following section.

9.6 Economic impact modelling

A key aim of this study was to identify the economic benefits which could be experienced as a result of adoption of 5G technologies. This was done by drawing on the wider economic evidence base on 5G impacts, economic projections from CE’s MDM-E3 macroeconomic model, and various internal findings from other workstreams in this project (principally relating to adoption, barriers and total addressable markets). It important to again note that there is considerable uncertainty around the model results, which is the case for any forward-looking projection, but is especially true here due to the shortage of empirical evidence on 5G.

Cumulative total benefits were £41bn-£159bn

Key findings relating to economic benefits of 5G are summarised in Table 9-1. Depending on the technology assumptions (GPT or ADT), the total benefits were found to be £41bn-£159bn cumulatively over 2021-35.

The 'Smart urban' consumer group had registered the largest economic benefit

Due to the pace of adoption coupled with the economic size of these consumer groups, Smart urban, Public services and Manufacturing, logistics and distribution have the largest cumulative benefits in levels terms under the GPT scenario (£58bn, £39bn and £15bn respectively). However, in proportional terms (i.e. % difference from baseline) High speed broadband to homes and offices and Media and entertainment experience the largest impacts in proportional terms, because they are the most rapid adopters of 5G.

The ranking of impacts changes between GPT and ADT scenarios principally because of fundamental assumptions about the total addressable market. By definition, 5G is assumed to be “general purpose” under the GPT scenario and the share of the market which is addressable is proportionately the same across consumer groups. In contrast, there is greater variation in the addressable market share across consumer groups in the ADT scenario, with Rural industries, Retail and hospitality and Manufacturing, logistics and distribution having appreciably lower GVA impacts as a result.

Table 9-1 – Central economic benefits (£2018bn, cumulative, 2021-35)

	General purpose technology	Advanced digital technology
Total	**159.4**	**40.7**
Smart urban	57.9	17.9
Public services	39.1	8.7
Manufacturing, logistics and distribution	14.8	3.3
Retail and hospitality	12.6	1.5
High speed broadband into homes and offices	12.4	3.7
Media and entertainment	9.8	3.0
Transport	7.0	1.4
Energy and utilities	4.8	1.0
Rural industries	1.1	0.1

Economic benefits could be £22bn-£84bn higher if market barriers are addressed

The study also found that economic benefits could be extended by a further £22bn-£84bn over 2021-35 if market barriers are addressed, therein highlighting the role of policy in fully realising 5G benefits. The additional benefits from a reduction in market barriers is shown in Table 9-2.

Based on assessments of market barriers across scenarios, Smart urban and Manufacturing, logistics and distribution stand to gain the most from lowering market barriers (£17bn-£58bn additional economic benefits would be realised from reducing 5G market barriers in these two consumer groups).

Table 9-2 – Additional benefits from a reduction of market barriers (£2018bn, cumulative, 2021-35)

	General purpose technology	Advanced digital technology
Total	+83.7	+21.6
Smart urban	+45.6	+14.0
Manufacturing, logistics and distribution	+12.5	+2.8
Retail and hospitality	+8.2	+0.9
Public services	+8.0	+1.8
Transport	+3.1	+0.6
High speed broadband into homes and offices	+2.5	+0.7
Energy and utilities	+2.4	+0.5
Rural industries	+1.5	+0.2
Media and entertainment	+0.0	+0.0

Digital intensity can provide further insights on the distribution of benefits

The study extended the analysis by considering how the share of benefits attributed to each consumer group might vary depending on digital intensity. This line of analysis provided insight into how each consumer group's relationship with digital technology may affect impact potential of 5G.

High speed broadband in homes and offices and Media and Entertainment both register considerably higher economic benefits under this alternative measure (+£17bn and +£14bn, respectively under the GPT scenario). Manufacturing, logistics and distribution and Transport, however, both register lower impacts under the alternative measure (-£7bn and £4bn, respectively under the GPT scenario).

5G adoption will positively impact GVA in all UK regions and countries

This is indicative of the breadth of 5G use cases across consumer groups. The largest impacts are estimated in London (£42bn in the GPT scenario and £12bn in the ADT scenario), the South East (£23bn in the GPT scenario and £5bn in the ADT scenario) and the South West (£15bn in the GPT scenario and £4bn in the ADT scenario), though this is mainly driven by the size of these regions. Likewise, the largest regions would realize the largest benefits from removing barriers to adoption.

There is variation in impacts between regions and countries in relative terms

While some regions have more to gain than others from removing market barriers, all regions could experience significant gains. Measured as change in % difference from the economic baseline, the impacts range from 0.59pp (London) to 0.47pp (Northern Ireland) in the GPT scenario and 0.18pp (London) to 0.10pp (Northern Ireland) in the ADT scenario by 2035.

The main driver of variation in relative sub-national impacts is the roll-out of 5G.

Urban areas within-each region and country are expected to benefit more strongly from 5G because it will be rolled out there first. GVA gains in urban areas are projected to range from 0.59pp (London) to 0.51pp (Northern Ireland) in the GPT scenario and from 0.18pp (London) to 0.12pp (Northern Ireland) in the ADT scenario.

In the ADT scenario, impacts are markedly lower in rural areas

However, rural areas are still expected to benefit strongly from 5G adoption in the GPT scenario, where adoption is widespread across consumer groups. In the ADT scenario, impacts are markedly lower in rural areas, as a result of lower adoption in smaller businesses and in some consumer groups (including rural industries) which account for a relative high share of economic activity in rural areas. Therefore, while rural impacts are lower than urban impacts, the results indicate that 5G adoption will be important to rural economies in the GPT scenario where 5G use cases are broader than for previous mobile technologies.

Hence, impacts of removing barriers are lower in rural areas

GVA gains in rural areas in 2035 are projected to be around 10-18% lower in the GPT scenario and 25-40% lower in the ADT scenario (with the exception of London).

Private networks may be particularly important for rural areas

The model results indicate that private networks may be particularly important to rural areas. This result is driven by two factors: the slower roll-out of public networks stimulating demand for private networks as an alternative; and rural areas having a relatively high share of firms in consumer groups, which favour the specific use cases for which private networks offer an advantage. Private network adoption was modelled as exclusive to Manufacturing, logistics and distribution and energy and utilities best on our mapping of the use cases best supported by private networks discussed in Section 3.2 to the consumer groups, together with an analysis of the firms that have set up private networks in the UK to date, which largely fall within these two consumer groups.

9.7 Environmental impact modelling

We modelled avoided emissions brought about by IoT machine to machine use cases and smartphone use cases.

The way in which 5G use leads to emissions savings depends on the types of use case:

- IoT machine to machine use cases such as those in buildings, transport, manufacturing, and the energy sector, will enable emissions savings through improved efficiency.
- In addition, smartphone 5G use cases will enable emissions savings through behavioural changes (e.g. more online shopping, use of transport apps increased public transport use, etc,).

The GPT scenario projections should be viewed as a lower bound

The projections in this model are based on current use cases for mobile network technology which are hence most likely a sub-set of the future use cases through which 5G could lead to lower emissions. 5G as a GPT technology would have a much wider set of use cases than 4G, but we do not yet have empirical data on the potential for these use cases to lower emissions.

Up to 184 million tonnes of CO2 could be saved due to 5G adoption over 2021-35

Up to 184 million tonnes of CO2 could be saved due to 5G adoption over 2021-35 according to the GPT scenario results. This emissions saving is around 30% greater than in the ADT scenario, though as noted above, the emissions savings from a GPT scenario could be far greater depending on the avoided emissions factors of the use cases that emerge in this scenario.

Avoided emissions are greatest in consumer groups for which 5G improves transport efficiency or reduces travel

Both the findings from our literature review of environmental benefits of 5G and the results from the modelling indicate that the greatest environmental benefits relate to use cases which improve transport efficiency or reduce travel. Examples of such use cases include smart logistics and traffic congestion management (transport consumer group), smart working use cases (high speed broadband into offices and home consumer group), and mobile shopping applications (retail and hospitality consumer group).

Removing barriers would have larger impacts in Rural industries, Manufacturing, logistics and distribution, Smart urban and Energy and utilities

Consumer groups for which business use cases were modelled are projected to realise relatively higher emissions savings as a result of removing market barriers, with the highest potential savings in rural industries (73%), manufacturing, logistics and distribution (41%), smart urban (33%) and energy and utilities (32%). In these consumer groups, emissions saving 5G use cases are mainly business use cases whereas in the other consumer groups, the modelled use cases are largely 5G consumer smartphone applications, which have been modelled as having lower market barriers in the central case.

9.8 Social impact modelling

We modelled time savings enabled by 5G

The literature review found multiple channels through which 5G will bring social benefits, such as improvements in public safety, improved healthcare and time savings. However, limited evidence exists on the potential magnitude of the majority of these benefits. Therefore, modelling undertaken in this study was limited to estimating the value of time saved on housework and family care by individuals. The evidence suggests that 5G-enabled features of personal and household IoT devices will result in greater efficiency when doing housework and family care, leading to time savings.

Removal of 5G market barriers could result in up to £2.4bn of additional social benefits

The model estimates (Table 9-3) show that under the General-purpose technology scenario assumptions, the cumulative value of time saved between 2020 and 2035 will reach £19.7bn in the central market barrier case, and £22.1bn in the low market barrier case. This means that under the GPT scenario removing the barriers to adoption of 5G could potentially unlock £2.4bn of additional benefits to individuals.

In the advanced digital technology scenario, the cumulative value of social benefits is estimated at £14.9bn in the Central market barrier case, and at £16.7bn in the Low market barrier case. Therefore, under the ADT scenario, removal of barriers to 5G adoption could result in £1.8bn of additional social benefits to individuals.

Table 9-3 Cumulative value of social benefits (£bn, 2021-35)

	General purpose technology (GPT) scenario	Advanced digital technology (ADT) scenario
Central market barrier case	19.7	14.9
Low market barrier case	22.1	16.7

Source: Modelling by Cambridge Econometrics and Analysys Mason.

These estimates are sensitive to the choice of 5G additionality assumption

These estimates are subject to large uncertainty and are particularly sensitive to the assumed additionality of 5G-enabled features of personal and household IoT devices. The study relies on a lower-end estimate of 5G additionality from the literature (attributing only 5% of the potential savings from personal and household 5G-enabled IoT devices to 5G-enabled features). Future research could seek to establish validity of such assumptions, for example by surveying consumers on the value of specific 5G-enabled features of their household and personal devices.

As more evidence becomes available, future research could estimate the social benefits of improved public safety and healthcare

Further research should also aim to explore the methods of valuing other social benefits of 5G, such as improvements in public safety (improved monitoring) and healthcare (patient monitoring). Currently, the evidence on such benefits is available from small trials which may not be representative of the potential benefits when 5G is deployed on a wider scale.

At the same time, estimates of such benefits also need to address the issue of identifying the additional value of 5G in these applications. Applications relating to public safety or healthcare could potentially be supported (fully or with limited features) by existing technologies, such as 4G or Wi-Fi. Therefore, only the additional social benefits enabled by 5G should be identified in these estimates.

Appendices

Appendix A Acronyms and Glossary

A.1 Acronyms

3GPP	3rd Generation Partnership Project
5GTT	Testbeds and Trials Programme
AGV	Autonomous guided vehicle
AI	Artificial intelligence
AR	Augmented reality
B2B	Business-to-business
B2B2C	Business-to-business-to-consumer
B2C	Business-to-consumer
BNetzA	Bundesnetzagentur
CEPT	European Conference of Postal and Telecommunications Administrations
DCMS	Department for Digital, Culture, Media and Sport
eMBB	Enhanced mobile broadband
FTIR	Future Telecoms Infrastructure Review
FWA	Fixed wireless access
IoT	Internet of things
LoRa	Long range
LPWAN	Low-power wide-area network
LTE	Long-term evolution
LTE-A	LTE-advanced
MBB	Mobile broadband
MIMO	Multiple-input multiple-output
mMTC	Massive machine type communications
MNO	Mobile network operator

MR	Mixed reality
NB-IoT	Narrowband-IoT
NR	New radio
NSA	Non standalone
OTT	Over the top services
PoC	Proof of concept
QoS	Quality of service
RAN	Radio access network
RFDI	Radio frequency identification
ROI	Return on investment
SA	Standalone
SIM	Subscriber identity module
SLA	Service level agreement
SME	Small medium enterprise
TCO	Total cost of ownership
UAV	Unmanned aerial vehicles
UHD	Ultra-high definition
URLLC	Ultra-reliable low-latency communication
V2X	Vehicle-to-everything
VoIP	Voice over Internet Protocol
VR	Virtual reality
XR	eXtended reality

A.2 Glossary

3G RAN	3rd generation of a radio access network (RAN). (ICF 2020)
4G RAN	4th generation of a radio access network (RAN). (ICF 2020)
5G application	Groups of 5G use cases.
5G RAN	5th generation of a radio access network (RAN) (ICF 2020)
Backhaul	In telecommunications, 'backhaul' refers to a communications link connecting the base station to the core network which can transmit data at very fast speeds. Achieving the benefits of 5G will require changes in how a backhaul layer is built (such as multiplying the capacity). (ICF 2020)
Cloud computing	Cloud computing is the delivery of computing services – including servers, storage, databases, networking, software, analytics and intelligence – over the Internet ("the cloud") (Microsoft Azure 2021).
Edge computing	Edge computing enables low latency 5G applications by bringing computing capabilities closer to the application.
Enhanced mobile broadband	Enhanced Mobile Broadband is one of the three primary 5G New Radio use cases defined by the 3GPP as part of its SMARTER (Study on New Services and Markets Technology Enablers) project. The other two are URLLC and mMTC'. Both should be defined herein, although only URLLC appears in this report. (ICF 2020)
Fixed wireless	Fixed wireless is the operation of wireless communication devices or systems used to connect two fixed locations (e.g., building to building or tower to building) with a radio or other wireless link, such as a laser bridge. (ICF 2020)
Latency	Latency, in technical terms, is a time interval between the cause and the effect of some physical change in the system being observed. 5G is designed significantly to reduce network communication delays (latency). Latency has held back technologies that are otherwise technologically ready for 5G. (ICF 2020)
Machine to machine communication	A broad label that can be used to describe any technology that enables networked devices to exchange information and perform actions without the manual assistance of humans (ICF 2020)
mmWave	Millimetre wave (millimetre band) (also known as 'extremely high frequency) is the band of spectrum between 24 gigahertz to 100 GHz. These high-frequency bands are referred to as 'mmWave' due to short wavelengths that can be measured in millimetres. 5G wireless broadband technology is being tested on millimetre wave spectrum and can be used for very high-speed wireless broadband communications (ICF 2020)
Mobile edge-cloud	Mobile Edge Cloud (MEC) is a network architecture concept that offers a cloud-like capability at the edge of the network. Being close to the end

	users, MECs decrease the latency and increase the performance of high-bandwidth applications (Torre, Doan and Salah 2020).
NarrowBand-IoT	NarrowBand-IoT (NB-IoT) is a standards-based low power wide area technology developed to enable a wide range of new IoT devices and services. (ICF 2020)
Network sharing	Network sharing e.g. for MNOs means they are sharing the infrastructure to some degree or other. (ICF 2020)
Network slicing	Network slicing capabilities (born through 5G networks) will support the provision of end-to-end dedicated capacity and tailored uplink/download speeds Network Slicing is a network architecture that enables service providers to build virtual end-to-end networks tailored to application requirements – the ability to deploy only the functions necessary to support customers and market segments. (ICF 2020)
NR-Light	Reduced capability NR devices
Radio access network	The RAN consists of the parts of the network associated with radio transmission, reception and signal processing which enable wireless communication with the mobile phone or other terminal device. (ICF 2020)
Release 15/16/17	Release 15 is the first full set of 5G standards, includes the 5G system phase 1, machine type of communications, IoT, vehicle to everything communications, WLAN and unlicensed spectrum and system enhancements. Release 16 is the second phase. New features include enhancement of ultra-reliable low latency communications, satellite access in 5G, streaming and TV (ICF 2020) Release 17 is the third phase.
Radio frequency identification	Refers to low powered radio systems used for equipment tagging and tracking, typically using spectrum identified for "short range device" use
Spectrum	The 5G spectrum is a range of radio frequencies in the sub-6 gigahertz range and the millimetre-wave frequency range that is 24.25 GHz and above. The 5G spectrum involves the radio frequencies that carry data from user equipment (UE) to cellular base stations to the data's endpoint. (ICF 2020)
Virtualisation	Virtualisation refers to the core networks of 5G being implemented in software, rather than in hardware.
XR	eXtended reality, including augmented reality AR, virtual reality VR and mixed reality

Source: Analysys Mason

Appendix B Adoption curves

Table B-1: Projected UK-wide adoption in the GPT and ADT scenarios, central market barrier case

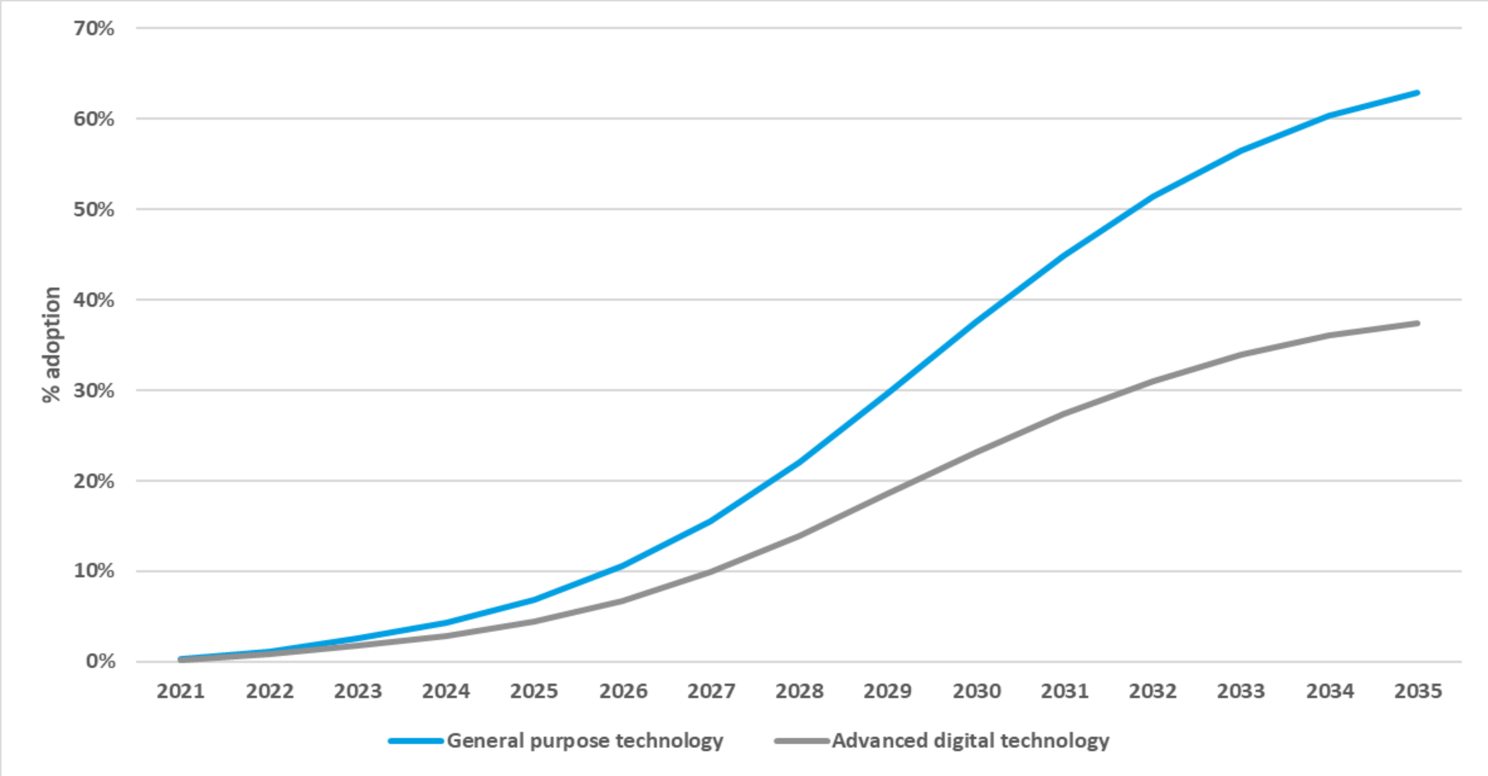


Table B-2: Projected adoption in each UK region and country in the GPT scenario, central market barrier case

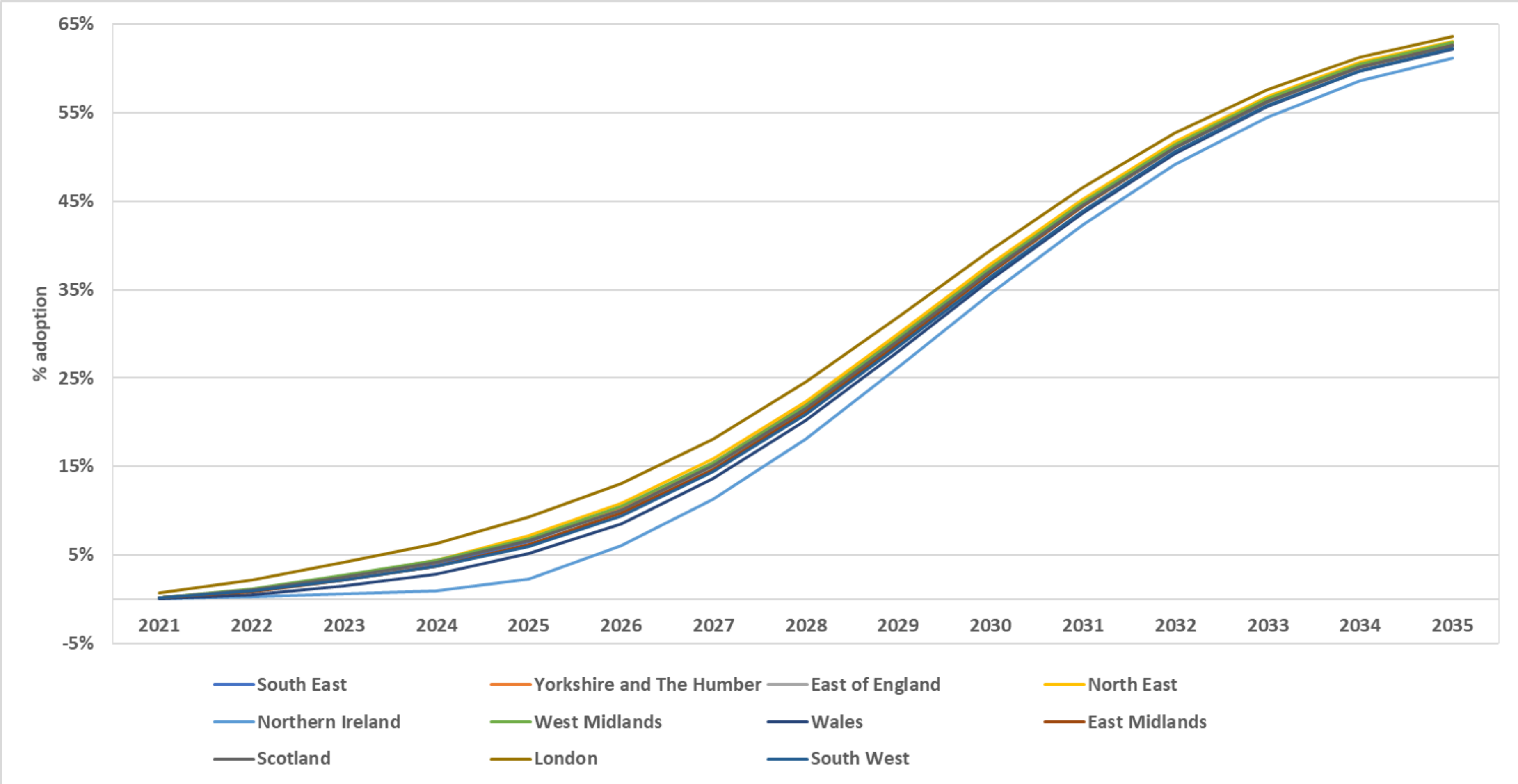
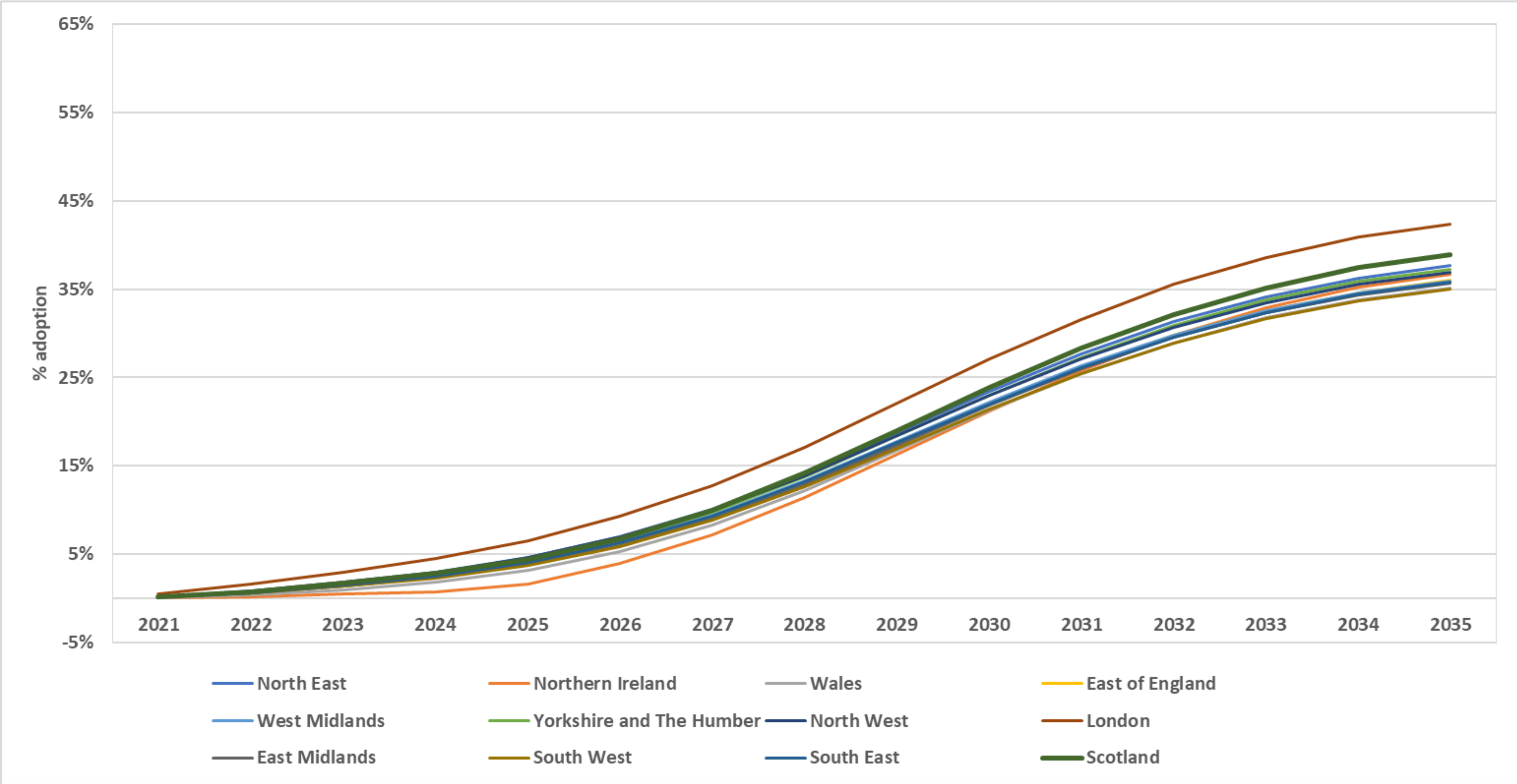


Table B-3: Projected adoption in each UK region and country in the IoT scenario, central market barrier case



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