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Cebr
Making Business Sense

Full fibre broadband: A platform for growth

A Cebr report for Openreach

October 2019

Connecting you to your network

www.openreach.co.uk

Openreach Limited
Registered office: Kelvin House, 123 Judd Street, London WCIH 9NP.
Registered in England and Wales no. 10690039.
Produced by Openreach.
Printed on recycled paper.
Designed by Chilliblossoms Limited.
OP1.1910.0093.

Authorship and acknowledgements
This report has been produced by Cebr, an independent economics and business research consultancy established in 1992. The views expressed herein are those of the authors only and are based upon independent research by them.

The report does not necessarily reflect the views of Openreach.
London, October 2019

About

Cebr

For over 25 years the Centre for Economics and Business Research (Cebr) has supplied independent economic forecasting and analysis to hundreds of private firms and public organisations, combining robust economic analysis with a solid understanding of how to present insights in a meaningful, clear way. Cebr delivers award-winning forecasts of the UK and global economies and has advised several government departments as well as FTSE and multi-national firms on a range of topics. Cebr regularly uses innovative methodologies to quantify the economic contribution of new technologies and other aspects of the economy that are difficult to quantify.

Our recent work includes economic impact assessments for a range of proposed or existing fiscal and other policy measures, sectoral economic impact studies, and broader transport and housing infrastructure projects. We have worked on many and varied themes, including:

- Crossrail 2 Economic Impact Report – producing a comprehensive evidence base on the economic benefits of a major rail scheme (TfL, to inform DfT's advice to ministers);
- Housing policy requirements to unlock transformational growth in the Northern Powerhouse (Homes for the North, aimed at influencing MHCLG);
- The economic impact of the arts and culture sector in England (Arts Council/DCMS);
- Maximum stakes for Fixed Odds Betting Terminals (BACTA). This provided evidence to supported the recent legislative changes made in this sector;
- Alcohol minimum unit pricing (Molson Coors);
- The impact of a Digital Services Tax;
- The effect of alcohol duties on the UK economy (Scotch Whisky Association);
- Restrictions on placement of unhealthy food in the retail sector (General Mills);
- The economic impacts of the UK maritime sector (Maritime UK);
- Transitional costs of renationalising the prison probation service (Probation Service, aimed at DoJ).

Openreach

Openreach Limited is the UK's digital network business.

We're 33,000 people, working in every community to connect homes, schools, shops, banks, hospitals, libraries, mobile phone masts, broadcasters, governments and businesses – large and small – to the world.

Our mission is to build the best possible network, with the highest quality service, making sure that everyone in the UK can be connected. We work on behalf of more than 620 communications providers like Sky, TalkTalk, Vodafone, BT and Zen, and our fibre broadband network is the biggest in the UK, passing more than 27.6m UK premises

Over the last decade we've invested more than £13 billion into our network and, at more than 173 million kilometres – it's now long enough to wrap around the world 4,314 times.

Today we're building an even faster, more reliable and future-proof broadband network which will be the UK's digital platform for decades to come.

Contents

Openreach Foreword

Clive Selley
CEO Openreach

Full fibre is the UK's digital future. It will provide people with more reliable, faster, and future-proof broadband.

And I'm convinced that the technology it enables will become the backbone of our national economy, supporting every aspect of our daily lives for decades to come.

This report highlights the benefits that full fibre will bring – billions of pounds in productivity gains, jobs created throughout the country and people better able to live and work in rural communities.

It highlights how working patterns will shift, where people live could change, with benefits that could be realised in every region of the UK.

At Openreach, we're excited to be leading the way in making this vision a reality. We have the ambition to connect the whole country to full fibre and we've already reached more than 1.8 million homes and businesses. Our engineers are building this new network to more than 22,000 premises each week – that's a home every 28 seconds – and we're continuing to increase the size and scale of our deployment. We're on track to reach four million premises by March 2021 and, with the right support, I believe we can continue to scale-up our build to three million premises a year.

It is crucial that no area of the UK is left behind. Openreach is particularly committed to improving the quality of rural connectivity and we're the only digital infrastructure provider doing that at any significant scale. This report highlights how full fibre offers one of the quickest, most effective ways to boost productivity – not only in London and the South East – but across the country. Whether it's enabling people to work from home, to relocate or return to the workforce, rural economies have the potential to benefit enormously.

Full fibre connectivity is essential to future-proofing our economy. It will ensure the UK can be competitive on the world stage, especially important as we leave the European Union. And it will unlock the next generation of technological innovation, allowing our digital economy to continue flourishing.

Building the new network across the UK won't be quick or easy. It requires a physical build to more than 30 million front doors, thousands of skilled engineers and billions of pounds of investment. Without the right policies and regulations, there's a real risk we'll fall behind other nations and fail to unlock the benefits that better, more reliable broadband can bring to the whole country.

The National Infrastructure Commission (NIC) estimated that the total level of investment required for nationwide full fibre will be in the region of £33 billion. With the right policies and regulations in place, the private sector will be responsible for the vast majority of that investment. That means comparatively low levels of public subsidy will be required. And in contrast to other major infrastructure projects such as Heathrow and HS2, there is cross-party support for accelerating full fibre deployment.

Deploying full fibre offers benefits as we build, not just when we've finished, and for every community in the UK. That's why today we've also published a blueprint setting out what's needed to underpin an acceleration in our deployment. It highlights some of the changes that will be required, working with industry, Government and Ofcom, and sets out our role at Openreach in enabling this to happen.

This report highlights the prize for the whole country if Government and Ofcom can help clear the barriers to a nationwide full fibre rollout. We're proud to be leading the charge and playing our part in such a transformational change – for communities, consumers and businesses across the country.

Executive Summary

The UK is on the cusp of a transformative upgrade to its digital infrastructure. Openreach, and others, are in the process of ramping up their deployment of full fibre across the country.

The radically increased reliability and speed which full fibre offers compared to existing infrastructure will underpin new ways of doing business, delivering public services and participating in the workforce – and will deliver significant benefits to consumers at home too.

There is considerable uncertainty around how significant these impacts will be. As a result, we have taken a conservative approach in our analysis, and present different scenarios for the potential economic impacts based on different assumptions about how radically full fibre will affect productivity.

In our baseline model, we use the observed impact which the rollout of ultrafast broadband has had in the limited number of areas where it has been deployed. However, it is possible that the impacts will be more substantial.

As a result, we have also modelled what could happen if full fibre has a more transformative impact on the UK economy. We have used the widespread introduction of information communication technology in the 1990s as representation of this. We have also considered what the potential impacts would be if the deployment of full fibre represents a truly transformational change on par with the delivery of the railway and canal systems, which radically alters the productivity of the UK workforce.

Despite using a conservative approach as the basis for our model, the outputs remain significant. In this report, we set out how full fibre could improve labour productivity and enable more people to work from home. We also highlight a number of additional impacts, such as a potential reduction in congestion and pollution. Being able to work from home has two main effects – firstly to allow for a rebalancing of employment opportunities, but also to bring new groups into the workforce.

- **Productivity:** Under our baseline assessement, we forecast a **gross value added (GVA) uplift of £59 billion by 2025**, if deployment is completed at that point – with benefits continuing to rise after deployment is complete. We have also modelled the impacts of completing nationwide deployment at later points to provide an indication of the respective levels of benefits which could be delivered.
- **Regional rebalancing:** More reliable and faster broadband will make it easier for people to work from home, rather than commuting into an office each day. This could have major implications for where people are able to work and live. This report shows that **over 400,000 more people could be enabled to work from home if they choose to do so** compared to existing trends, and that this could be accompanied by changes in where they choose to live; our model suggests a transfer of population away from London and the South East.

  This could reinvigorate rural communities which are currently suffering from depopulation and declining availability of social infrastructure – and relax housing affordability and transport constraints in major urban centres, as people choose to move around the country and into rural communities.
- **New working opportunities:** The opportunity to work from home could also enable people to enter, re-enter, or remain in the workforce for longer. We look at the impact of being able to work from home on the employment choices of carers, the over-65s, and new parents. The analysis suggests that over **500,000 people who may otherwise not have worked could now find attractive employment opportunities**. Again, the economic impact of increased workforce participation could be significant, even under conservative assumptions about employment choices.

Full fibre broadband: a platform for UK growth

£59bn

boost to UK productivity by 2025
powered by nationwide rollout of full fibre

300m
commuting trips saved

by people working from home because of full fibre including three billion kilometres fewer travelled by car

500k

back in to the workforce

Nationwide full fibre could bring half a million people back into the workforce by 2038

Nationwide rollout of full fibre could increase productivity by

£1,800
per person

270k

people could move to rural areas

People free to live and work where they choose because of full fibre, helping to fuel growth

400k

more people could work from home

400,000 more people could work from home helping people to avoid the commute, and have greater choice about where they live

£70bn

boost to the economy by 2038

Nationwide rollout of full fibre broadband will boost the UK economy by £70 billion by 2038

2021

video will make up 80% of all internet traffic in the UK†

Data usage is growing 40% each year, mainly driven by people watching on-demand TV like Britbox and Amazon Prime. By 2021, video will make up 80% of all internet traffic in the UK.†

2021 82.5m VR/AR headsets will be sold

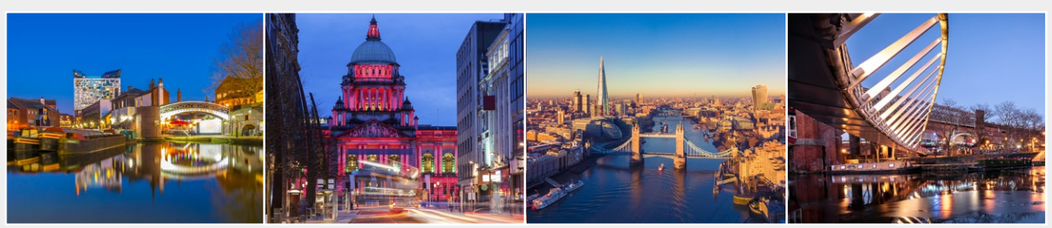
By 2021 it is expected that 82.5 million VR/AR headsets will be sold and shipped around the world. This compares to 70.6 million PlayStation 4 units being sold from its launch in 2013 to 2017 globally.

FTTP is a full fibre line which runs all the way from the exchange to your home or business. Because it's not affected by the weather like copper lines can be, it's also far more reliable – so your signal won't cut out or 'buffer'.§

For many businesses, high value work is being conducted in rural and remote locations. This includes the 91% of farm businesses that say that broadband is an essential tool for them to run their business.‡

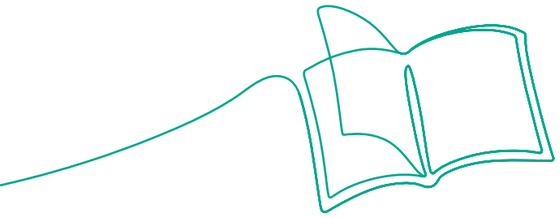
103 locations

103 locations have now been included in Openreach's multi-billion-pound Fibre First build programme, including the UK's biggest cities (Birmingham, Belfast, London, and Manchester)¥



† Openreach, Future-proofing the UK: Our annual review 2018/19
§ Openreach, '*Ultrafast full fibre infrastructure for smaller new build sites*'
‡ Confederation of Business Industry, Ready, Set, Connect: Delivering a roadmap to supercharge the UK's digital infrastructure, (7 December 2018)
¥ Openreach, 'Futureproof broadband coming to 29 new locations as Openreach accelerates its nationwide build programme', (02 October 2019)

Key findings



01

Economic impacts

- We have modelled the potential productivity impacts of completing a nationwide full fibre deployment by 2025, 2028, 2030 and 2033. This offers a range of different potential impacts depending on when nationwide full fibre can be deployed;
- We have also taken a scenario based approach to model differing outcomes – reflecting the uncertainty in how full fibre could affect the economy in the long term;
  - If deployment is completed in 2025, under our conservative baseline assumption, GVA is boosted by £59 billion, rising to over £70 billion in 2038. Under our baseline model, a slower rollout will ultimately have the same impact on labour productivity, but at a slower pace;
  - GVA impacts in Scotland, Wales, and Northern Ireland are £4.6 billion, £2 billion, and £1.3 billion respectively.

02

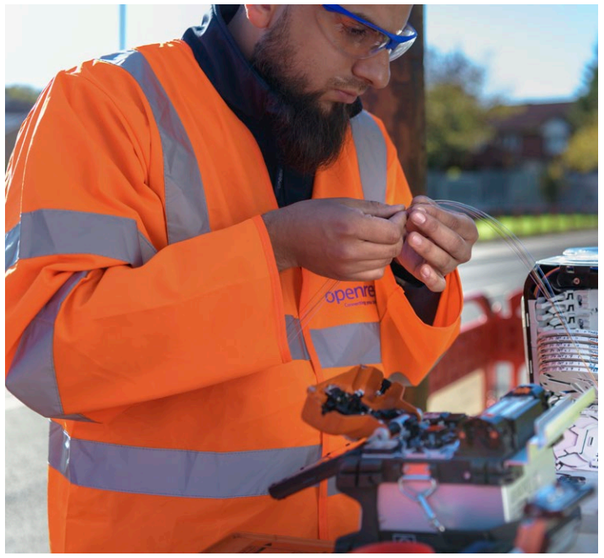
Regional impacts

- Enhanced opportunities for remote working could reduce transport and housing pressures in big cities as workers are able live further away from work. This will also support the economies of parts of the UK which currently perform less well;
- With radical improvements in connectivity we estimate that the UK could see:
  - **400,000 additional people could be enabled to work from home with full fibre by 2033** compared to our baseline scenario – with 1 million people in total having the opportunity to work from home compared to our baseline;
  - **Over 270,000 people could potentially move away from London and other major cities** and into suburban and rural areas, compared to our baseline. Over 93,000 more people could choose to work in rural communities compared to the present day;
  - Non-metro areas across the North could see significant boosts in residential levels – with over 43,000 more people choosing to live in these areas compared to our baseline;
  - The value of the additional time saved from reduced commuting levels could equate to almost £3 billion in additional GVA by 2038;
  - This could save 300 million commuting trips, representing a carbon reduction of 360,000 tonnes.

03

Workforce impacts

- Nationwide full fibre deployment could bring **over 500,000 new workers into the workforce** through allowing them to work from home by 2038. In total, over 700,000 people could increase their working hours;
- These increases in working hours could have a GVA impact of over £15 billion annually;
- We estimate that over 450,000 people who are currently carers could be enabled to enter, or reenter the workforce as a result of full fibre, or to increase their working hours;
- Almost 150,000 over-65s could continue to work, or could set up their own business;
- Over 125,000 women with dependent children could be supported to re-enter the workforce;
- The largest relative gain is in the North East – where a 1.7% increase in employment could be produced through bringing new entrants into the workforce.



Introduction

Over the last three decades, services underpinned by the internet have transformed society and the economy, just as canals and railways did during the nineteenth century.

Digital connectivity is critical for UK consumers and is a major source of strength for the economy. One third of Europe's fastest-growing tech companies are based in Britain[1] and the digital sector contributed £130.5bn to the UK economy in 2017, representing 7.1% of total GVA.[2]

However, in order to meet the continuously growing demands on the existing network, upgrades are now required to future-proofed the network and to ensure the UK can continue to maintain this success.

Full fibre broadband will be the most effective and cost-efficient way of delivering this future-proofed upgrade. The previous Government published the Future Telecoms Infrastructure Review (FTIR)[3] in 2018, which set an ambitious target of delivering nationwide full fibre by 2033[4], with an interim goal of covering 15 million premises by 2025.

The FTIR saw private sector investment, underpinned by a competition focussed regulatory regime, as the key driver for delivering this goal. The FTIR set out plans to reduce the costs network operators face when deploying full fibre, while looking to the private sector to then invest to deploy these networks across most of the country.

The Government also recognised that targeted government investment would be required to support deployment in areas where the private sector was unlikely to invest. These would largely be rural areas where the cost of deploying infrastructure is so high that it would be commercially unviable for any operator to invest.

Many of the legislative changes which the FTIR planned are still being developed, but remain critical to help network operators deploy at pace and scale. New regulatory measures will also be required to make less competitive areas more attractive for investment.

Following the change of Prime Minister in July 2019, the Government is now suggesting that a more ambitious pace of rollout is required, with the aim to deliver gigabit-capable networks across the country by 2025.

The industry is currently working with Government to assess whether, and how, this goal can be achieved. It is clear that meeting this ambition will require further action by Government to help speed up the pace of deployment, along with delivery of the previous policy commitments that have been made.

Openreach has set out some of these steps in the blueprint which has been published alongside this report. While meeting this goal will require a cross industry effort, Openreach will be at the forefront of delivering the Government's ambition. Their current goal is to deploy full fibre to four million premises by March 2021, with the ambition to pass 15 million premises with full fibre by the mid-2020s, if the conditions are right. While other operators will also play a role in upgrading the UK's digital infrastructure, Openreach's investment will ultimately be responsible for delivering the majority of build in the UK.

Why full fibre is important

Compared to the existing infrastructure which currently covers almost every property in the UK, the expected impacts of upgrading this network to full fibre can be summarised as:

- **Significantly improved available upload and download speeds,** helping consumers and businesses through enabling them to download and upload files to and from the internet far more rapidly than currently available. With gigabit speeds, it will be possible to download an HD movie in under 30 seconds, as opposed to over four minutes with a 100Mbps service. Consumers will also be able to more effectively run multiple devices via their connection – allowing for multiple streaming services and connected devices to be used simultaneously. It has been estimated that the number of devices per household will rise from 9.5 in 2016 to 16 devices by 2021.[5] For businesses, symmetric upload speeds will help with large file transfers and using cloud based services;
- **Significantly improved reliability,** leading to far fewer faults for consumers and businesses – with potentially five times fewer faults compared to a copper network[6]. Enhanced reliability will mean even more applications can be supported by the network, and lead to fewer times when the network is unavailable. Fewer faults will also make running the network cheaper, which will help keep costs low for industry and consumers. Improved reliability will also support increased remote working – enabling more and more people to work from home if they wish to. Healthcare monitoring, and other applications which need to work continuously, will be better supported through full fibre;
- **Greater capacity which can support future increases in data requirements**. A full fibre network can be upgraded easily, meaning that once the fibre has been deployed, it will can be upgraded relatively simply to meet any future connectivity requirements. In effect, this will future-proof the network for the foreseeable future – providing a foundation for future growth and prosperity. Other technologies which can currently deliver ultrafast speeds will require more extensive work to provide additional speed increases in future;
- **Speeds that are less variable according to location**, with rural areas having the same speeds as urban areas. Removing copper from the network will mean that even the most remote communities will have access to gigabit speeds. This will help rural areas which have previously generally not had access to the same speeds as urban areas – closing the digital divide and allowing businesses and consumers across the country to compete on a level playing field. Our research sets out in more detail how rural communities across the country could be supported through improved connectivity;
- **Lower network latency**, which will allow for the smoother and quicker transfer of data. This will help new applications to be supported, including virtual and augemented reality, online gaming and the Internet of Things (IOT). It has been predicted that traffic from virtual and augmented reality will increase twelve-fold between 2017 and 2022.[7] Medical advances – such as remote diagnostics – and autonomous vehicles will both require low latency connections in order to effectively function.

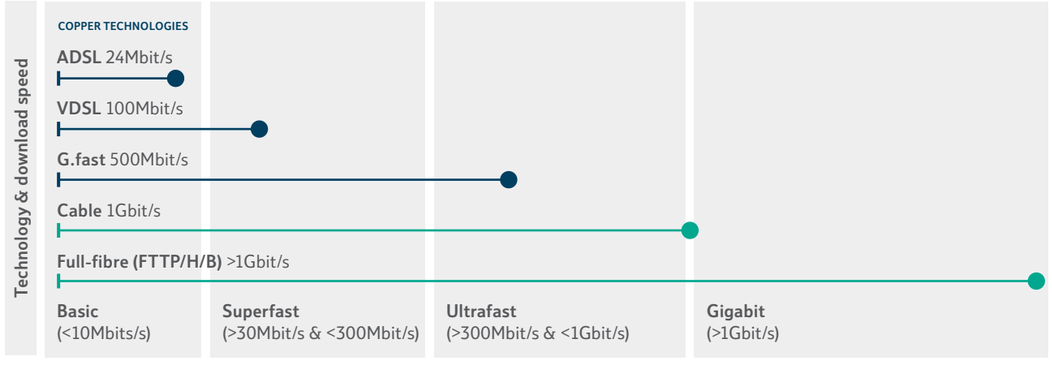
The responses of consumers, businesses, and the public sector to the opportunities created by these changes will determine the extent of these benefits. In fact, the emergence of demand will to a significant extent depend on the development of services that are themselves stimulated by future opportunities that are only made possible by full fibre – in effect a virtuous circle as greater take-up drives innovation and new ways to use it, increasing the benefits and therefore future adoption of full fibre broadband.

How broadband is delivered

Broadband is currently available across a range of different infrastructures. These are summarised below:

- **Basic broadband (ADSL)** is delivered by a copper line linking a property to the exchange, via a cabinet. This has generally been phased out across the country as superfast networks have been deployed, although a small percentage of premises have not yet been upgraded;
- **Superfast broadband (VDSL) / fibre to the cabinet (FTTC)** has been deployed as an upgrade to the old copper network across much of the country. Fibre is laid from the exchange to the cabinet, with copper then being used to link individual properties to the cabinet. Speeds degrade quickly depending on the length of the copper, meaning speeds are dependent on how close the property is to the street cabinet. Uploading a 1GB file would take an estimated seven minutes on average;
- **G.Fast** was launched by Openreach as an upgrade to the FTTC network. It delivers speeds of 500Mbit/s or more over a copper connection of about 100 metres. While a cost effective means of boosting speeds, it lacks some of the benefits that a full fibre network produces, such as enhanced reliability;
- **Cable networks** can be upgraded relatively inexpensively to provide gigabit speeds. Any further speed increases would require much more substantial and expensive upgrades to the network, meaning it is less future-proofed than full fibre. Whilst the latest cable upgrade will be capable of delivering 1Gbit/s download speeds, it provides poorer upload speeds compared to full fibre. It is however comparatively difficult to deploy additional capacity to alleviate network slowdown at busy times. The cable network is also concentrated in urban areas, with little chance of nationwide deployment;
- **Full fibre / fibre-to-the-premises (FTTP)** removes all of the copper in the network. This infrastructure offers the highest speeds (over 1Gbit/s download and upload), 'future-proofing' with potential for relatively easy additional upgrades, impressive reliability, and can be significantly cheaper to maintain than legacy copper networks. Deployment is typically more expensive than more incremental upgrades to the existing network. However, the benefits it will offer mean this is the best technology to use in the long term. Compared to the seven minutes taken to upload a 1GB file on the superfast network, a full fibre connection would take around 42 seconds[8].

FIGURE 1: Overview of fixed broadband technologies



Digital services can also be accessed via mobile connectivity. Mobile operators are in the early stages of deploying 5G networks. At present, these networks are being deployed in small areas of larger cities, but will gradually be deployed into wider areas. 5G will rely on fibre connections to work effectively regardless.

Fixed wireless access technologies also offer ways of accessing the internet. At present, it does not offer an equivalent performance to full fibre – with lower speeds and latency being key features. The coming introduction of 5G could however transform this proposition and offer a viable competitor to fixed connections – although 5G coverage will need to improve rapidly for this to take place.

The UK's digital infrastructure in context

In the 2018 National Infrastructure Assessment, the NIC highlighted that:

> The UK already has a strong digital economy underpinned by an extensive superfast broadband network. There is room for improvement on mobile coverage and rural connectivity but, in general, the UK's digital connectivity meets the needs of today's consumers. The UK compares well internationally for superfast broadband availability, but trails behind other countries such as Spain and Sweden for full fibre availability.[9]

According to the independent monitoring website ThinkBroadband, as of October 2019, of all UK premises:[10]

- 2.6% currently cannot access decent broadband speeds, and would be eligible to request an improved service under the Universal Service Obligation;
- 96% had access to superfast speeds in excess of 24Mbit/s;
- 58% had access to ultrafast speeds in excess of 100Mbit/s;
- 9.4% can access full fibre services.

The UK compares well on many measures to other countries in Europe, with one of the highest levels of superfast broadband availability.[11] However, penetration of full fibre or other ultrafast technologies lags some of our competitors.

The UK's position in an international context is therefore somewhat ambiguous – superfast coverage is widespread and provides sufficient connectivity for the requirements of most households at the present time. Relatively few households, however, can access the very highest speeds via full fibre – highlighting the need for further investment to upgrade to full fibre.

To further complicate the picture, take up of superfast services has not been universal, despite concerns of the pace of the superfast rollout. Even today, millions of residential premises where superfast broadband is available have not upgraded their service; just 55% of premises covered under the publicly funded BDUK (Broadband Delivery UK) Phase 1 and 40% of premises covered under BDUK Phase 2 have adopted superfast services.[12] For the benefits of full fibre to be fully realised, this will need to change with far greater take-up.

Future demand

The FTIR set out why the move to full fibre will be important, stating that "*when looking at the speed, resilience and reliability that consumers will rely on and businesses will need to grow, it is clear that full fibre and 5G is the answer. Wide-scale deployment of these next generation technologies will be key to the UK remaining globally competitive, and support the regional rebalancing of the economy by creating new opportunities, in areas like health, education and public services.*"

The NIC also noted that there is considerable uncertainty around future bandwidth requirements, but recognises that *"it is possible that bandwidth demand could exceed the capabilities of a copper network within the 10-20 year horizon required to rollout a full fibre network"* under its higher growth projections.

Streaming services adding Ultra HD options, virtual and augmented reality applications, the Internet of Things (IOT) devices, and connected and autonomous vehicles will all be sources of demand with high growth potential but which rely on high, consistent speeds.[13] The data being carried over the current network is growing by 40% year on year.[14]

Many innovations in the provision of Government services, including in health and education, will increasingly be underpinned by full fibre. Beyond the consumer benefits this will deliver, the public sector will be able to provide more personalised and higher quality services at the same or reduced cost.

Service reliability will also be important in supporting these higher bandwidth applications. As applications powered by digital become even more integral to consumers' personal and professional lives, it will become even more important that the infrastructure supporting them is highly reliable with low fault rates.

With this in mind, future demand should not be seen as fixed – rather as being something that will adapt to the infrastructure available, offering more and better services as the network develops.

The potential for infrastructure to deliver transformative and unexpected benefits – and for demand for connectivity to grow rapidly if supply permits – therefore supports the case for Government to stand behind the industry to deliver an inclusive full fibre network. Moreover, although it is inherently risky, there is no viable alternative to investing in anticipation of future demand, given the time lags that are involved – the alternative of not investing is more costly when the likely foregone benefits are fully considered.

The previous focus on delivering superfast broadband has provided a strong interim solution for the UK. But to continue to be internationally competitive, and to provide a platform for the coming wave of new technologies, we need to accelerate the deployment of full fibre in order to ensure that current strong UK performance is maintained into the future.

Infrastructure investment and uncertainty

All types of infrastructure investment schemes share certain common characteristics relating to the nature of uncertainty, and these need to be recognised in the way they are appraised:

- infrastructure is not 'consumed' for its own sake. Rather it is a means to an end and the benefits it provides need to be considered in terms of the services it facilitates by firms and individuals. Its provision is necessarily social however, as high fixed costs have to be shared among large numbers of people, to whom it is provided in a common way, rather than being optimised to the needs of each individual (although some forms of business connectivity are more tailored than other types of infrastructure provision). It is therefore necessary to forecast demand across large numbers of users – which is inherently uncertain;
- there are significant time lags in planning and construction that mean decisions must be made with regard to long term demand forecasts, which the infrastructure provided may either fail to meet or overprovide for, should the anticipated demand not materialise;
- the nature of future benefits are to some extent unknowable. In the eighteenth and nineteenth centuries, canals and railways – the new communications technologies of their day – brought transformative economic and social change, chiefly rapid industrialisation and urbanisation, the nature and scale of which could not have been anticipated at the time of their introduction.

This last point is particularly relevant in the case of full fibre. The services that it will facilitate could bring about fundamental shifts in the structure and performance of the UK economy – which could also be manifested in changes in the ways in which people live and work.

Much of this change will rely on applications that may not have been developed yet, so there is clearly significant uncertainty in relation to the nature of future uses of the network – and also in the nature and scale of the resulting economic impacts.

We can however use economic theory and the existing evidence base to develop an approach that captures the likely range and nature of the effects and provides a basis for estimating their scale.

Our overall approach

Given the significant uncertainty about the nature and scale of the likely benefits outlined above, it is not possible to produce a single definitive view of the future economic benefits of the full fibre rollout.

We have therefore built a picture of the likely impacts through a number of different perspectives, using a mixture of economic modelling and other quantitative and qualitative analysis, drawing on a range of different approaches. We organise this as follows:

- **Productivity and employment impacts:** how overall economic performance at the national level could be boosted, for example through promoting innovation, enabling faster uptake of new technologies, increased competition, reduced barriers to trade and so on;
- **Spatial impacts:** likely changes in the organisation of economic activity and patterns of work, for example, greater opportunities for small businesses and for people to work remotely which will affect patterns of economic

geography. To the extent that full fibre availability tackles constraints on the nature and scale of economic activity that takes place in particular locations by unlocking their 'economic potential', it could not only facilitate higher overall growth but play a significant role in spreading prosperity more evenly across the country, reducing gaps between:

  - different regions of the UK, in particular London and the South East and the rest of the country;
  - urban and rural locations, through enabling a greater spread of activities traditionally concentrated in cities;
  - the increasingly dynamic city regions and 'left behind' towns that have not fully recovered from earlier structural economic shifts in UK competitiveness;

- **Workforce impacts:** impacts on different groups, including older workers, carers and women with dependent children, who can be expected to benefit from improvements in access to opportunities and therefore be more likely to participate in the labour market;
- **Wider social impacts:** non-monetised benefits will not be reflected in GDP estimates (which will capture most of the above effects). These include increased leisure time and the availability of better choices for how people use their leisure time and improvements in quality of life arising from increased flexibility in where they can live, and so on.

We consider impacts on different sectors of the economy in more depth through five detailed case studies looking at health, education, creative industries, manufacturing and rural industries (including agriculture and tourism). These will be presented in separate supplementary reports.

We have also looked at some of the wider policy implications and possible social benefits of the deployment at the end of this report. We cover a range of broad policy areas that will need to be integrated with the programme in order to ensure both that the full benefits are realised and that any potentially adverse indirect effects are mitigated.

Overarching economic impacts

Key findings

01 We have modelled the potential productivity impacts of deploying nationwide full fibre by 2025, 2028, 2030 and 2033. This offers a range of different potential impacts depending on how quickly full fibre can be deployed;

02 We have also taken a scenario based approach to model differing outcomes – reflecting the uncertainty in how full fibre could affect the economy in the long term;

03 If deployment is completed in 2025, under our conservative baseline assumption, GVA is boosted by £59 billion, rising to over £70 billion in 2038. Scenarios modelling more substantial impacts suggest that the GVA impact could be over £131 billion by 2038.

Introduction

There is a wide body of literature assessing the potential impacts of improved digital connectivity on labour productivity.[15] We have drawn on recent studies of the impacts of digital infrastructure in the UK alongside historic evidence available from past periods of rapid development and deployment of different communications technologies.

The statistical evidence on recent digital infrastructure upgrades provides a good foundation for estimating the general productivity effects that could result from full fibre deployment. Previous research has largely focussed on the impact of providing superfast broadband, rather than assessing the additional impact of full fibre over and above that achievable with superfast. However, recent work has also looked at the productivity impacts of more dramatic increases in available speeds.

Given the transformative and unpredictable impact that the internet has already had on the economy, precisely quantifying these impacts is difficult, but we have endeavoured to use the most robust evidence base available. We've taken a scenario-based approach to recognise the potential divergence in outcomes, rather than attempting to set a single figure for what the long term impacts of full fibre could be.

Previous research commissioned by the Department for Digital, Culture, Media and Sport (DCMS) has been used to form our baseline scenario. Upper bound estimates were obtained through the application of historical evidence on radical improvements in different forms of connectivity – offering potential models for how full fibre could have a more substantial impact on the economy.

The extent to which these higher estimates are achievable will ultimately depend on decisions taken by policymakers, business owners, and the individuals who make use of the upgraded network.

Reviewing these evidence sources has also allowed us to consider some of the economic impacts which could take place. The types of productivity effects that may occur include:

- **time savings** as processes are sped up, freeing up time for other activities;
- **changes to the structure of economic activity** – including a shift to more productive activities, and an acceleration of existing trends towards higher-skilled work;
- **higher levels of innovation** in the economy and better application of technology;
- **more competitive firms** – lower cost, better managed firms winning higher market share through improved access to potential customers;
- **agglomeration effects through clustering** – knowledge spillovers, better labour market matching, and more efficient sharing of resources.

Selection of labour productivity assumptions

Evidence on available speeds and firm productivity

A 2018 report for DCMS[16] estimated the impacts on firm performance from the superfast broadband rollout. Its approach was based on analysis of the Business Structure Database, which records employment and turnover for all VAT or PAYE-registered companies. A comparison of this data with postcode data on superfast broadband rollout was used to estimate employment and productivity effects.

The paper also included research into the impact of more substantial speed increases in areas where this has occurred.[17] It found that for firms benefitting from a 200 to 500 Mbit/s increase in maximum available download speeds, the estimated incremental impact on turnover per worker was 3%.[18] We therefore assume that once deployment has been completed, labour productivity will be 3% higher than forecast without it.

There are some aspects to the approach which are worth discussing here:

- turnover per worker is used as a proxy for GVA per worker (i.e. productivity). This is a reasonably good proxy but effects on productivity may be overstated if for example greater connectivity enables greater outsourcing, which would boost turnover per worker but not productivity;
- effects are evaluated at the local level, so applying raw results is likely to overstate the national impacts of digital infrastructure improvements. Greater sales and employment by firms located in areas benefitting from increased available speeds may come at the expense of firms elsewhere, and higher productivity firms may relocate into these areas. Therefore significant displacement will occur when speeds increase in selected areas, and net national impacts will consequently be lower than these results suggest. To address this issue, DCMS isolated and presented results for firms that did not change location. We can be more confident that productivity improvements here are a better representation of the potential impact on productivity. The 3% figure we use is for firms that did not change location – without introducing this control, DCMS found impacts as high as 3.8%;
- inevitably, areas receiving large increases in maximum available download speeds will not be representative of the country as a whole. DCMS noted that postcodes receiving 100MB to 200MB connectivity enhancements were concentrated in core and secondary cities; those receiving 200MB to 500MB enhancements were largely in the East Riding of Yorkshire or Kingston upon Hull (delivered by K-Com); and those receiving enhancements of 500MB or more were mainly rural, with the exceptions of York, Bournemouth, and Peterborough postcodes.

The 3% figure was used as the DCMS approach represents the most comprenhensive and robust available model. Nevertheless, our literature review indicated that even around this baseline there is considerable uncertainty about the effect of significant increases in available speeds on labour productivity. For example, Fabling and Grimes (2016)[19] find that fibre adoption does not in isolation boost productivity. By contrast, Akerman et al. (2013)[20] studied data from Norway and found that broadband adoption increases the productivity of skilled labour by more than 20% whilst slightly reducing the productivity of unskilled labour – a potentially much higher effect depending on the skill profile of the economy.

DCMS did not find that enhanced connectivity boosted overall employment in the postcodes studied, and Fabling and Grimes also did not find a statistically significant overall employment impact. On this basis we do not assume any general increase in employment to accompany the general increase in productivity. Research from Canada has however suggested that fibre deployment to 100 percent of a region is associated with an increase in employment of approximately 2.9 percent[21], so it is quite possible that new business creation and additional employment as a result of enhanced connectivity will take place.

While we do not allow for such a general employment impact resulting from full fibre, we have instead focussed on other ways in which labour supply will be affected. In particular, we estimate labour supply impacts for different groups who currently find it difficult to participate in the labour force but could be enabled to do so through improved connectivity. Overall productivity estimates factor in the value of additional hours worked, and our summary includes these employment effects.

Analytical approach

Cebr macroeconomic forecasts

Our analysis is based on Cebr's in-house macroeconomic forecasts of employment and productivity (GVA per worker), which we adjust to account for the effects of full fibre deployment based on our literature review and workforce impact estimates. Cebr's baseline productivity and employment figures are detailed macroeconomic forecasts, however they do not incorporate major infrastructure changes like a full fibre rollout. There is therefore no double-counting as a result of our changes to the model to reflect the effects of full fibre.

Inputs for scenarios around labour productivity growth

There is considerable uncertainty around the productivity impacts of transformative connectivity improvements. Given that future uses of full fibre are still in the early stages of development and their economic and social impacts remain uncertain, we think it is appropriate to take a scenario-based approach. We have modelled the impact of deployment being completed in 2025, 2028, 2030 or 2033.

There is clear evidence that past improvements in connectivity driven by communications and transportation technology have delivered increases to labour productivity through their effects on competition, trade, innovation, and agglomeration. We have used some of these previous impacts as proxies for the potential different impacts of full fibre under different scenarios.

Scenario A: We assume that on completion of the full fibre rollout, labour productivity is **3%** higher than forecast based on the observed improvement in labour productivity from previous DCMS research.[22] Productivity growth rates in the years leading up to complete rollout (i.e. from 2020 to 2025, 2028, 2030, or 2033) are adjusted accordingly to achieve this result. This provides results for our 'baseline' productivity gains.

Following a review of the relevant literature, we draw on two different studies to give 'upper bound' productivity estimates. Enhanced estimates are based on more rapid labour productivity growth once rollout has been completed, which result in:

Scenario B: A review of information technology and its contribution to US economic growth in the 1990s found that, on average, ICT equipment accounted for **3.7%** of the growth in labour productivity from 1991 – 1998.[23] Forecast productivity growth rates after completion of rollout are therefore increased accordingly[24] in this scenario.

We have used this figure for Scenario B on the basis that it offers a rough analogy to the potentially significant productivity impacts which full incorporation of digital technology could provide to businesses.

Scenario C: We consider the possibility that the delivery of full fibre will trigger longer term productivity impacts on the scale of the creation of the railroad and canal system. A wide-ranging review of historical evidence regarding the economic impacts of transport investments estimated that at their peak, railways increased labour productivity growth in the UK by **25%**.[25] Under this scenario we therefore increase forecast labour productivity growth rates by 25% once rollout has been completed.

While this estimate is clearly at the highest end of potential productivity increases, the comparison serves to demonstrate the implications for labour productivity if full fibre has a truly transformative impact on the UK's economy.

Take-up assumptions

As our scenarios are 'top down' rather than 'bottom up', we do not take a view about *whose* productivity responds to FTTP rollout. This is important as it is very likely that there will be significant differences in the incremental productivity effects of full fibre between different people and firms.

We can confidently expect that the people and firms that stand to gain the most from the use of FTTP will be among the first to take it up. Moreover, given that the nature of future uses to which FTTP will be put remain uncertain, the degree to which diminishing returns will set in is not yet known. For example, it is highly likely that say 90% of the possible benefits of FTTP will be achieved with a take-up rate that is far lower than 90% – but what take up rate would in fact generate this proportion of the realisable benefits? It is possible that some of the productivity benefits will be generated indirectly, e.g. by people who haven't themselves taken up full fibre services, whose ways of working wih other people are still transformed. In any case, even if there were a known relationship between take-up and productivity impacts, it would be difficult to accurately forecast take-up given that the UK is still in the early stages of deployment.

Given these circumstances, it seems more appropriate to base our productivity impact estimates on the *availability* of full fibre, for which there is more evidence. In particular, the DCMS research upon which our baseline estimates (Scenario A) are based relates to observed impacts of what actually occurred in the postcodes studied in response to the availability of higher speeds. Full fibre take-up is just under 30% among premises for which it is available[26] and the DCMS research takes no view as to how this would change.

Insofar as our baseline productivity work, Scenario A, is based on continuation of observed trends for the availability of full fibre, it can be interpreted as take-up continuing along these lines. It is a conservative approach insofar as it assumes no further productivity impacts once rollout is completed – either because take-up does not increase, or further increases in take-up do occur but do not spur higher productivity.

Scenarios B and C represent views of the future in which take-up is driven higher (though we do not make any explicit assumptions about the rate) through innovation which results from the availability of full fibre – therefore productivity benefits continue to emerge after rollout has been completed. Under these scenarios, the benefits of full fibre are higher than in Scenario A. It can therefore be assumed that these would be associated with significantly higher take-up rates than Scenario A, and growth in take-up over time as innovation generates additional benefits, spurring greater adoption – hence the increased growth in labour productivity after rollout is completed under Scenarios B and C.

This is reasonably consistent with the assumptions of a 2018 Regeneris report on the economic impact of full fibre[27]. This report assumes a 35% adoption rate after five years, achievement of productivity benefits one year after adoption, and realisation of innovation benefits four years after adoption. Technological change and Metcalfe's Law[28] are assumed to slightly increase the productivity and innovation impacts, with the uplift increasing over time. In this work, the baseline impact is implicitly based on slightly lower take-up (around 30%, as quoted in the DCMS study). The Regeneris methodology sees gradually increasing innovation impacts, analogous to the increased labour productivity growth after completion of rollout in this work.

The planned retirement of the copper network as set out in previous Openreach industry consultations suggests that take-up of full fibre should eventually be substantially higher than take-up of existing FTTC services. The sector is still working to plan for copper retirement, so we do not make assumptions about when copper retirement will take place in any given area. With a slower rollout, take up will be slower, delaying the full realisation of its benefits.

Incorporating workforce impacts

Estimated workforce impacts based on our spatial model and analysis (explained in more detail later in this report) affect both employment and GVA.

Total extra hours worked are based on the numbers of new home workers, older workers, carers, and parents we estimate will work additional hours, multiplied by the additional hours worked per year for each. These are valued at forecast GVA per hour.[29] In estimating employment impacts we assume that:

- 'new home workers' as predicted by our spatial model are all people who would be in the workforce anyway, but switch to mainly working from home as a result of full fibre. Therefore they do not have an effect on total employment;
- half of the carers who work additional hours are new to the workforce, the other half are people who were employed anyway but take the opportunity to increase their hours. Therefore the employment impact is 50% of the number of carers increasing their participation;
- all the older workers and working parents who increase their participation are new to the workforce, so the employment impact is 100% of the workers affected.

As with the baseline productivity effects, workforce impacts are phased in during rollout, and are fully realised once it is completed. In the years before completion of rollout, the realised benefit is a proportion of total potential benefits.[30]

Modelled outputs

In this report, we therefore estimate the economic impacts of full fibre rollout through:

- 'top-down' increases in labour productivity across the economy, according to three scenarios (A, B, and C – with A the 'baseline' and B and C based on more optimistic assumptions about the impact of improved digital connectivity);
- increased hours worked by those who work from home more in response to full fibre rollout, based on the outputs of our spatial model;
- increased labour force participation and hours worked by groups who stand to benefit from greater availability of flexible and remote working (the older generation, those with caring responsibilities, and parents).

There are clearly other potential benefits which full fibre could deliver, some of which were summarised at the start of this chapter. The key results on GVA, productivity (GVA per worker), and employment from our model are summarised summarised in the following tables.

Table 1 shows the estimated productivity impacts in 2025, 2028, 2030, 2033, and 2038 of the full fibre rollout if deployment is completed in 2025.

Under this model, with our conservative baseline assumptions, GVA is boosted by £59 billion in 2025, and by over £70 billion in 2038. Additional workforce impacts from bringing new people into the workforce could increase GVA by an additional £16 billion in 2025, rising to £18 billion by 2038.

In our most optimistic scenario, labour force and productivity impacts combined could increase GVA by over £150 billion in 2038.

Delivering full fibre by this date would be a significant achievement, and will be highly challenging to accomplish. The manifesto which Openreach has published today demonstrates some of the core policy and regulatory changes which are required in order to help industry deliver this – but even with these changes, delivering will be difficult.

TABLE 1: Summary of estimated economic impacts, 2025 rollout (2017 £)

		2025	2028	2030	2033	2038
Productivity scenario A	GVA (£ million)	£59,030	£61,694	£63,472	£66,264	£70,881
	GVA/worker (£)	£1,748	£1,789	£1,814	£1,856	£1,931
Productivity scenario B	GVA (£ million)	£59,030	£63,496	£66,467	£71,287	£79,834
	GVA/worker (£)	£1,748	£1,841	£1,900	£1,996	£2,175
Productivity scenario C	GVA (£ million)	£59,030	£73,850	£83,707	£100,280	£131,756
	GVA/worker (£)	£1,748	£2,141	£2,393	£1,996	£3,589
Workforce	GVA (£ million)	£16,145	£16,724	£17,132	£17,724	£18,504
	Employment	475,583	483,867	490,741	498,497	500,661

Table 2 shows the estimated impacts in 2025, 2028, 2030, 2033, and 2038[31] if the full fibre deployment is completed in 2033. It sets out GVA and GVA per worker impacts of general improvements in productivity under each of the three scenarios, plus the GVA and employment impacts of the workforce effects.[32]

The effects of the different productivity scenarios only emerge after rollout is completed in 2033, reflecting the longer-term impact on innovation. In the most optimistic case for 2038[33] national GVA is approximately £95 billion higher, with workforce impacts adding an additional £18 billion in GVA. GVA per worker is over £2,500 higher, and more than half a million more people are in employment.

TABLE 2: Summary of estimated economic impacts, 2033 rollout (2017 £)

		2025	2028	2030	2033	2038
Productivity scenario A	GVA (£ million)	£11,646	£26,204	£39,675	£66,264	£70,881
	GVA/worker (£)	£345	£760	£1,134	£1,856	£1,931
Productivity scenario B	GVA (£ million)	£11,646	£26,204	£39,675	£66,264	£74,452
	GVA/worker (£)	£345	£760	£1,134	£1,856	£2,028
Productivity scenario C	GVA (£ million)	£11,646	£26,204	£39,675	£66,264	£95,008
	GVA/worker (£)	£345	£760	£1,134	£1,856	£2,588
Workforce	GVA (£ million)	£6,919	£10,751	£13,461	£17,724	£18,504
	Employment	203,821	311,057	385,583	498,497	500,661

A comparison of the impacts of 2033 and 2025 rollout in Table 3 shows that, considering 2025 rollout relative to 2033 rollout:

- employment impacts in 2033 and 2038 are the same, however the accelerated programme means full employment impacts have been realised by 2025[34];
- GVA impacts for Scenario A are the same in 2033 and 2038, however they are significantly higher in 2025 if rollout is accomplished by then – for the 2033 rollout programme full benefits are yet to be realised;
- under productivity Scenarios B and C, benefits are higher for all years. This is due to innovation effects which kick in once rollout is completed – in this case they occur eight years sooner with persistent effects on productivity growth. In the most optimistic case, Scenario C, rolling out full fibre by 2025 rather than 2033 results in GVA being nearly £37 billion higher and GVA per worker being over £1,000 higher.

TABLE 3: Comparison of estimated additional economic impacts of 2025 rollout compared to 2033 rollout (2017 £)

		2025	2028	2030	2033	2038
Productivity scenario A	GVA (£ million)	£47,384	£35,490	£23,797	£0	£0
	GVA/worker (£)	£1,403	£1,029	£680	£0	£0
Productivity scenario B	GVA (£ million)	£47,384	£37,292	£26,792	£5,024	£5,381
	GVA/worker (£)	£1,403	£1,081	£766	£141	£147
Productivity scenario C	GVA (£ million)	£47,384	£47,646	£44,032	£34,016	£36,747
	GVA/worker (£)	£1,403	£1,382	£1,259	£141	£1,001
Workforce	GVA (£ million)	£9,226	£5,973	£3,671	£0	£0
	Employment	271,762	172,810	105,159	0	0

The impacts of completing the rollout in the intermediate years of 2028 and 2030 are shown in Table 4 and Table 5 respectively. In both these models, the benefits of full fibre are delivered more rapidly than under a 2033 rollout.

TABLE 4: Summary of estimated economic impacts, 2028 rollout (2017 £)

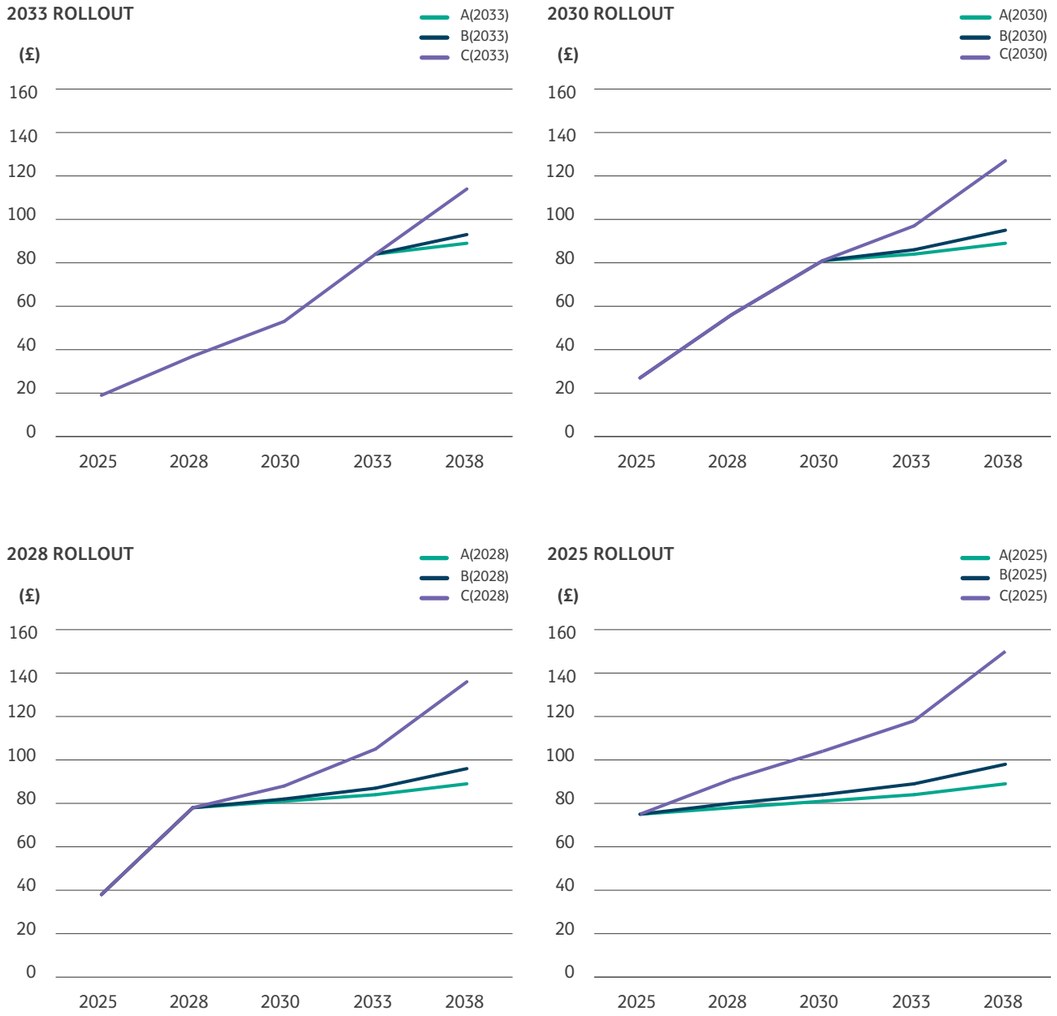
		2025	2028	2030	2033	2038
Productivity scenario A	GVA (£ million)	£27,305	£61,694	£63,471	£66,264	£70,881
	GVA/worker (£)	£809	£1,789	£1,814	£1,856	£1,931
Productivity scenario B	GVA (£ million)	£27,305	£61,694	£64,612	£69,349	£77,757
	GVA/worker (£)	£809	£1,789	£1,847	£1,942	£2,118
Productivity scenario C	GVA (£ million)	£27,305	£61,694	£71,156	£87,103	£117,521
	GVA/worker (£)	£809	£1,789	£2,034	£2,439	£3,201
Workforce	GVA (£ million)	£10,764	£16,724	£17,132	£17,724	£18,504
	Employment	317,055	483,867	490,741	498,497	500,661

TABLE 5: Summary of estimated economic impacts, 2030 rollout (2017 £)

		2025	2028	2030	2033	2038
Productivity scenario A	GVA (£ million)	£18,566	£41,852	£63,472	£66,264	£70,881
	GVA/worker (£)	£550	£1,214	£1,814	£1,856	£1,931
Productivity scenario B	GVA (£ million)	£18,566	£41,852	£63,472	£68,157	£76,481
	GVA/worker (£)	£550	£1,214	£1,814	£1,909	£2,083
Productivity scenario C	GVA (£ million)	£18,566	£41,852	£63,472	£79,036	£108,806
	GVA/worker (£)	£550	£1,214	£1,814	£2,213	£2,964
Workforce	GVA (£ million)	£8,807	£13,683	£17,132	£17,724	£18,504
	Employment	259,409	395,891	490,741	498,497	500,661

Figure 2 illustrates the impacts of different productivity scenarios and rollout years on national GVA.

FIGURE 2: GVA impacts (2017 £ billion), productivity by scenario and workforce combined



These estimates suggest that there are real benefits to accelerating the rollout of full fibre – turbocharging productivity across the country. Under more optimistic scenarios we see innovation benefits boosting productivity growth, so following a 2025 rather than 2033 rollout, GVA could be higher in 2038 by almost £37 billion. This would provide a significant boost to the UK for the long term.

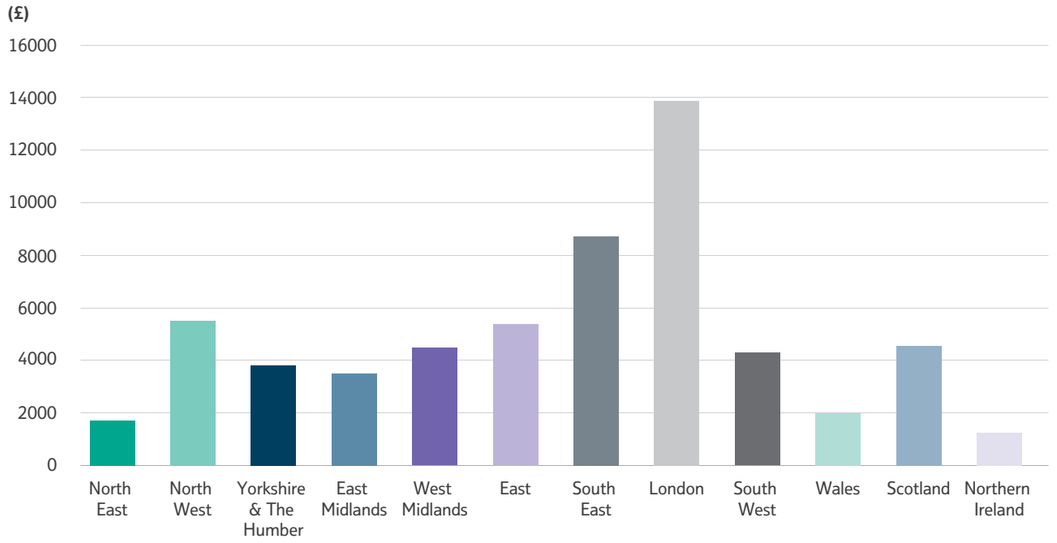
To meet this challenge, the delivery of full fibre will need to be significantly ramped up. Delivering this will require further support from both Ofcom and the Government, but our research demonstrates the potential win for the UK in following this approach.

Regional economic impacts

The productivity impacts of full fibre will be felt throughout the UK's nations and regions. Figure 3 shows regional GVA impacts in 2025 for productivity scenario A.[35] The largest impacts are in the regions with the largest economies, the South East and London. All regions benefit however.

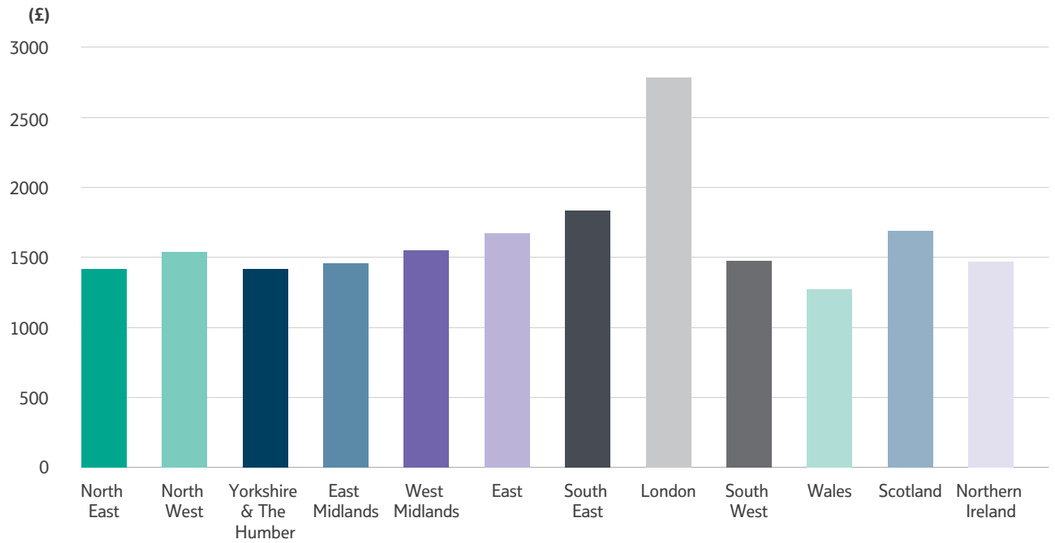
GVA impacts in Scotland, Wales, and Northern Ireland are £4.6 billion, £2.0 billion, and £1.3 billion respectively.

FIGURE 3: Regional GVA impacts (2025) under Scenario A (2017 £ million)



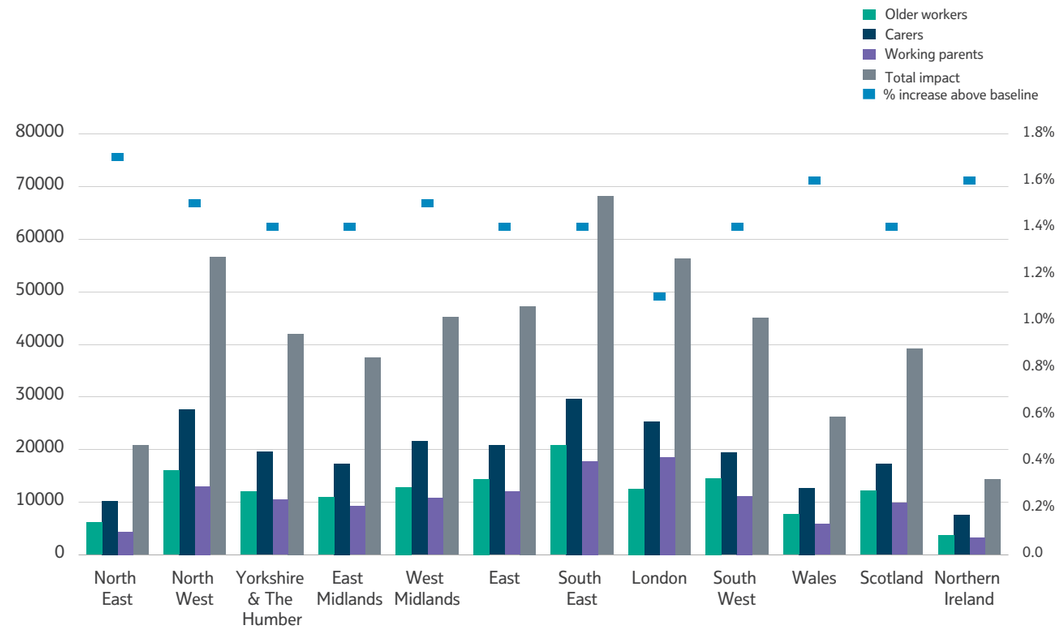
Productivity per worker impacts vary less across the regions, and reflect current levels of productivity. Therefore even under this relatively conservative scenario, London's GVA per worker stands to increase by nearly £3,000 and all regions see GVA per worker increase by at least £1,250.

Figure 4: Regional GVA per worker impacts (2025) under Scenario A (2017 £ million)



Full workforce impacts are realised in 2033 for completion of rollout in 2025, 2028, 2030, or 2033. Figure 5 summarises these on a regional basis and by category of those entering the workforce (older workers, carers, and working parents), showing both the absolute and relative increases in employment. With its relatively young population (and therefore fewer carers and potential older workers), London sees the smallest relative impact. Conversely, the biggest relative gain is in the North East, where the 21,000 additional workers represent a 1.7% increase in employment.

FIGURE 5: 2033 workforce impacts of full fibre rollout, including % uplift in regional employment



GVA impacts of additional workers are not broken down at the regional level. This is because – in no small part due to the remote working opportunities enabled by full fibre (as well as physical commuting e.g. from the South East and East into London) – workers are not necessarily employed in the region in which they live, so assigning these impacts to regions is not possible. New home workers predicted by our spatial model are also not included here, as they do not represent an addition to employment but a change in behaviour by those already in employment.

Spatial impacts

Key findings

01 400,000 additional people could be enabled to work from home with full fibre compared to our baseline scenario – with 1 million additional people in total having the opportunity to work from home compared to 2019. This could see 16.2% of UK workers having the opportunity to primarily work from home rather than commuting to an office;

02 With transformative improvements in connectivity, **over 270,000 people could move away from London and other major cities** and into suburban and rural areas, compared to the baseline analysis. Our alternative model suggests almost 175,000 people could leave metro areas in London, the West Midlands and across the North to move to more rural locations;

03 Non-metro areas across the North could see significant boosts in residential levels – with over 43,000 more people choosing to live in these areas compared to 2019;

04 Over 93,000 more people could choose to work in rural communities compared to the present day;

05 The value of the additional time saved from reduced commuting levels could equate to almost £3 billion in additional GVA by 2038;

06 This could save 300 million commuting trips annually, representing a carbon reduction of 360,000 tonnes.

Introduction

One of the potential impacts of full fibre deployment will be to make distance increasingly irrelevant, and allow for more work to be done remotely instead of in the traditional workplace. It is not just how people work that stands to change, but where they live, as physical proximity to centres of employment will matter less than ever.

To provide evidence-based estimates of how enhanced digital infrastructure could support these ambitions, Cebr has developed a model to simulate the choices made by individual workers over where to live, where to work, and whether or not to work from home.

This chapter provides an overview of how this model works, and considers the implications for a future in which remote working becomes more feasible.

Rebalancing the economy

Being able to work from home could enable more and more people to live further away from their place of work.

This could help to reinvigorate local and rural economies across the country – reversing current trends of rural depopulation. Beyond this, there is evidence that enabling remote working has real benefits for workers and their employers – with previous meta-analysis finding a small but positive correlation with productivity, levels of commitment, retention rates and performance.[36]

Successive Governments have highlighted the importance of rebalancing the economy away from London and the South East, and their desire to ensure that people and communities across the country are able to reach their full economic potential. It is widely believed that improved digital connectivity will play a critical role in this – and our research provides support for this. The new Government recently announced a new Towns Fund to attempt to stimulate and improve local economies.

Rural communities have often felt left behind when it comes to infrastructure investment. The Government has stressed the importance of taking an outside-in[37] approach to deploying full fibre – a goal which Openreach shares. Our research here highlights how rural communities could benefit.

Separate studies using different methodologies have found similar effects on home working to that which is presented below – a report commissioned for the National Infrastructure Commission suggested over 1.6 million people could potentially benefit from increased home working as a result of nationwide full fibre deployment.[38]

Research into the superfast rollout in Cornwall[39] found that improved connectivity helped employees to increase their hours of work from home. In the household survey, of the 41% of respondents who undertook work from home, 62% did so for more than one day a week after rollout, whereas only 28% did more than one day a week beforehand. The majority of these respondents said that superfast availability was important in their decision to work from home. Benefits included reductions in commuting miles and their associated environmental impact.

Other earlier research looked at the impact that superfast broadband could have on remote working. This estimated that faster broadband could add around 60 million hours of leisure time by 2024. The reduction in commuting costs was estimated to produce household savings of £270 million annually at the same time. The study also found that productivity benefits could reach £1.8 billion by 2024, and that roughly half of this would come from workers who lived in the three least dense deciles.[40]

Regional rebalancing

Globalisation has had profound implications for the structure of the UK economy, including marked increases in income and wealth inequality.

There has also been a spatial dimension to this. Large cities, in particular London, have competed effectively on the global stage and have become far more dynamic – but other areas have fared less well in competition with lower cost overseas locations and have lost some of their vitality, with resources and talent migrating to the larger cities.

The areas we expect to see more employment and in particular more residents as a result of full fibre rollout include those in the regions of Britain which perform relatively less well economically. For instance, much of the lower population areas which we see as disproportionately benefiting from full fibre rollout include the entireties of Wales, which scores relatively poorly on the Indices of Multiple Deprivation (IMD) relative to the rest of the UK[41], and the rural North.

This could make a major contribution to boosting overall output and productivity, both through increased employment and through more highly-skilled workers resident in these areas – even if their place of employment is elsewhere (i.e. in a major city), their spending on local services will support the local economy.

There is now a growing political consensus that intervention is needed to bring about more balanced and socially acceptable outcomes, including at a regional level. The focus is not on more ex post income redistribution but rather to influence the structure of the economy in a way that provides a more equitable distribution of rewards from economic activity. A more proactive industrial policy represents a key element of this, while the Northern Powerhouse, Midlands Engine and other regional initiatives aim to close the economic performance gap through coordinated strategic planning and investment across various policy areas, including digital connectivity, transport, skills and housing. Understanding how full fibre rollout can contribute to this process and how policy needs to react in order to unlock its full benefits should be treated as a high priority.

Quality of life factors are increasingly important in attracting and retaining a high skilled workforce. Places that are perceived to be less attractive to live in may be trapped in a cycle of low investment and few opportunities. In order to break the cycle it is likely that concerted and integrated long term action is needed. While there is some benefit in intervening to strengthen the local economic base, improving access to opportunities in other locations will also play a role.

For example, while northern city regions have succeeded in developing dynamic, knowledge-based economies in and around their city centres, smaller surrounding settlements have not recovered from earlier deindustrialisation, and this is partly due to a legacy of underinvestment in transport, housing and local amenities. Full fibre rollout can unlock opportunities in these types of locations but this is likely to be predicated on investment to address issues that currently limit the attractiveness of these locations as residential locations for workers and as places to invest. This indicates that rather than being a complete solution in itself, full fibre rollout will be a means of increasing the potency of an overall package of regional rebalancing policies of which it is an important constituent part.

Inputs, outputs, and parameters

The key inputs to our model are:

- Population and land area of each local authority, and their distances from each other, in order to categorise them into archetypal areas based on density and distance from London;
- 2011 Census travel to work data to create the commuting matrix between model zones and to calibrate the model against;
- National Travel Survey (NTS) data on the average number of days worked by full-time workers each week and on the average time and distance of people's commutes.

Unfortunately, comprehensive local authority data needed for this model was only available for England and Wales. Our estimates of potential spatial impacts in Scotland and Northern Ireland are therefore based on scaling the outputs of the model for comparable regions.

For the purposes of the model, English and Welsh local authorities were grouped into 11 categories. The characteristics of these area archetypes are explored in the following section.

As a hierarchical choice model, the model assumes that individuals first choose where (i.e. in which of the 11 types of area) to live, then where to work, and finally whether to mostly commute to work or mostly work from home. Individuals will make these decisions based on the desirability of living and working in each type of area and the relative costs of **physical commuting** to an office or workplace environment (in time and money terms) and **digital commuting** (i.e. the implicit daily cost of working from home).

It is to be expected that if the implied cost of digital commuting falls due to the increased availability of full fibre broadband, choosing residential and working locations which are further apart and mainly working from home will become relatively more desirable to workers.

Model parameters – such as the desirability of living and working in different areas and the cost of digital commuting – are calibrated according to 2011 Census data. This ensures that the model produces realistic results reflecting average commute lengths and the correct distribution of where people live and work. Calibration ensures that, for example, most workers do not work from home.[42]

Based on these assumptions, the implied cost of digital commuting is calibrated at £43.50 per day. This figure is best interpreted as a combination of all the costs of working from home faced by an individual, including:

- monetary costs of working from home not covered by their employer:
  - telecommunications;
  - setting up a home office;
- non-monetary costs, i.e. perceived disbenefits of working from home:
  - difficulty in collaborating with colleagues;
  - difficulty in line management oversight of junior colleagues;
  - concerns about being less well regarded by colleagues and superiors due to lack of presence and the possibility of being passed over for promotion as a result.

Introducing full fibre will reduce these costs – especially through quick upload and download of files and reliable video conferencing which will enable better management and collaboration. The non-monetary costs should probably be seen as more important than the direct monetary costs for workers – the increased viability of working from home will reduce them substantially.

There is also an opportunity cost in relation to working from home which full fibre could reduce, in terms of missed innovation opportunities. Collaboration tools could similarly reduce these perceived disbenefits and therefore reduce the perceived costs of working from home.

As the implied costs of digital commuting fall, the first people to switch to working from home will be those with the lowest costs of doing so relative to their costs of physically commuting to a place of employment, i.e. those who:

- have a job and company culture in which physical presence at an office is relatively less important;
- do not require extremely high internet speeds to effectively work from home, and were therefore able to do so without requiring access to superfast or full fibre broadband;
- have or are able to set up a pleasant home office;
- currently undertake particularly long, unreliable, stressful, or expensive commutes to work.

If the trend towards increased work from home is to increase, we would expect that an acceleration of technological progress, consistent with the deployment of markedly more powerful digital infrastructure, will be required.

Changes in the implied cost of working from home can be used to produce changes in the choices made and test different future scenarios. In principle, improved digital connectivity

supported by full fibre should reduce both the perceived disbenefits that home workers face and their telecommunications costs, bringing down the overall cost of working from home.

The key outputs of the model are:

- workers' residential choices between the 11 archetypal zones;
- workers' workplace choices between the 11 archetypal zones;
- workers' commuting choices – whether to mainly commute to work or mainly work from home.[43]

The changes in these outputs generated by changes in digital commuting costs indicate how full fibre rollout could change the spatial distribution of population and employment. Results are presented both for the archetype areas and for Wales and the English regions (including appropriate metropolitan / non-metropolitan splits) based on re-aggregation of these local authorities.

Model area archetypes

The area archetypes used in the model are shown below, including example local authorities, brief commentary, and the following summary statistics based on 2011 Census travel to work data for England and Wales[44]:

- **Resident workforce:** total number of employed people who live in this area;
- **Employees:** number employed in this area, including those who live there and work from home;
- **Home workers:** residents who work from home as a percentage of resident workforce;
- **London workers:** residents who work in London as a percentage of resident workforce.[45]

Non-London local authorities are categorised according to their population density and distance from London, using the below criteria:

Low density areas only exist at distance bands 3 and 4 as there are no local authorities with population densities this low less than 100 km from London. This exercise is driven by the population density of local authorities, and boundary effects mean that not every town or city appears in the density band which might be expected, as some authorities include significant amounts of 'hinterland' around the main settlement and others do not. Therefore while, for example, Norwich and Ipswich are 'high density', Chelmsford and Leeds are 'medium density'.

High density	More than 2,000 residents per square kilometre
Medium density	100-2,000 residents per square kilometre
Low density	Fewer than 100 residents per square kilometre

Distance band 1	0-50 kilometres from London
Distance band 2	50-100 kilometres from London
Distance band 3	100-150 kilometres from London
Distance band 4	150 kilometres or more from London

London

33 London Boroughs including the City of London, 12 inner boroughs and 20 outer boroughs.

All 33 London boroughs are included in this category. There are highly divergent areas in London, from inner London employment centres hosting high employment densities of knowledge-intensive industries and the densely-populated residential areas around them, to outer London areas with lower densities of population and employment and a mix of industries more in line with the national picture. Nevertheless, this approach was considered appropriate due to London's national importance as an employment centre and the willingness of worker to commute long distances to it. Unsurprisingly, a very high proportion of the workers resident in London are also employed there. Approximately half a million more people are employed in the capital than live there.

Resident workforce	Employees	Home workers	London workers
3,585,107	4,103,483	10.8%	92.4%

High density, distance band 1

Seven local authorities: Luton, Harlow, Stevenage, Watford, Slough, Epsom and Ewell, Crawley

This category includes the high-density centres immediately outside London. Large numbers of London commuters live here, but more people work than live in this zone overall, reflecting the ability of these centres to attract commuters from their hinterlands. A higher share of premises here get Internet speeds of 30 Mbit/s or above, suggesting that few people here have very poor connections.

Resident workforce	Employees	Home workers	London workers
347,021	377,698	8.4%	17.7%

High density, distance band 2

11 local authorities: Cambridge, Oxford, Reading, Brighton and Hove, Eastbourne, Hastings, Southend-on-Sea, Northampton, Havant, Rushmoor, Worthing

As high density areas relatively close to London, these areas include lots of London commuters, as well as settlements – particularly Cambridge, Oxford, and Reading – which are highly successful knowledge-intensive employment centres. Overall, these areas see net in-commuting, showing that these centres attract workers who live in the areas around them..

Resident workforce	Employees	Home workers	London workers
716,601	774,600	11.0%	5.7%

High density, distance band 3

Nine local authorities: Coventry, Ipswich, Leicester, Portsmouth, Southampton, Bournemouth, Cheltenham, Gosport, Oadby and Wigston

The towns and cities in this category are sufficiently far away from London that relatively few residents commute into it from them, and they have their own distinctive economic bases such as manufacturing (Coventry) and ports/logistics-based activity (Portsmouth, Southampton).

Resident workforce	Employees	Home workers	London workers
706,196	742,203	8.5%	1.1%

High density, distance band 4

33 local authorities including: Manchester, Birmingham, Liverpool, Newcastle, Cardiff, Sunderland, Blackpool, Lincoln, Norwich, Exeter, Plymouth, Derby, Stoke-on-Trent, Tamworth, Torbay, Wirral

This category is dominated by large cities in the North, Midlands, and Wales. These have varying economic fortunes and strengths, and draw in about 400,000 commuters overall.

Resident workforce	Employees	Home workers	London workers
3,539,425	3,964,406	8.3%	0.5%

Medium density, distance band 1

31 local authorities including: Chelmsford, Dartford, St Albans, Windsor and Maidenhead, Woking, Broxbourne, Medway, Reigate and Banstead, Thurrock, Chiltern, Elmbridge, Gravesham, Mole Valley

This category includes the parts of the capital's immediate commuter belt not captured in high density, distance band 1. It has the highest percentage of its residents working in London of any category other than London itself.

Resident workforce	Employees	Home workers	London workers
1,666,915	1,512,899	12.7%	24.9%

Medium density, distance band 2

43 local authorities including: Canterbury, Milton Keynes, Wokingham, Braintree, Chichester, South Cambridgeshire, East Hampshire, Lewes, Mid Sussex, Ashford, Bedford, Tendring, Wellingborough

A mix of London commuter towns, suburban/rural/coastal locations, and towns with their own distinct economic bases (i.e. Milton Keynes) feature in this category. A high incidence of home working could be due to the number of rural and coastal locations which are desirable places to live, but do not contain major employment centres.

Resident workforce	Employees	Home workers	London workers
3,539,425	3,964,406	14.0%	6.9%

Medium density, distance band 3

32 local authorities including: Peterborough, Wiltshire. Stratford-on-Avon, Swindon, Warwick, Dover, Thanet, East Dorset, South Norfolk, West Oxfordshire, Fenland, Isle of Wight, New Forest, Suffolk Coastal

Coastal locations which are dependent on tourism (e.g. Isle of Wight, Thanet, Suffolk Coastal) are well-represented, along with significant towns in the outer reaches of London's commuter belt.

Resident workforce	Employees	Home workers	London workers
1,820,744	1,730,275	12.9%	1.6%

Medium density, distance band 4

117 local authorities including: Leeds, Sheffield, York, Loughborough, Doncaster, Newport, Swansea, Warrington, Cheshire West and Chester, East Devon, Flintshire, Malvern Hills, Rossendale, Stroud, Wrexham

Significant towns and cities in the North, Midlands, and Wales which are not included in the high density category feature here along with traditional smaller industrial locations like Rossendale and Wrexham.

Resident workforce	Employees	Home workers	London workers
8,059,913	7,557,804	10.8%	0.4%

Low density, distance band 3

Three local authorities: Rutland, Breckland, Cotswold

The three authorities in this category are all relatively rural locations, with agriculture and tourism relatively important industries. The incidence of home working is higher than in any high- or medium- density location, though this may be due to the inclusion of farmers in those who work from home. This archetype area scores more poorly than any other on both measures of Internet speed.

Resident workforce	Employees	Home workers	London workers
111,665	103,391	17.1%	1.4%

Low density, distance band 4

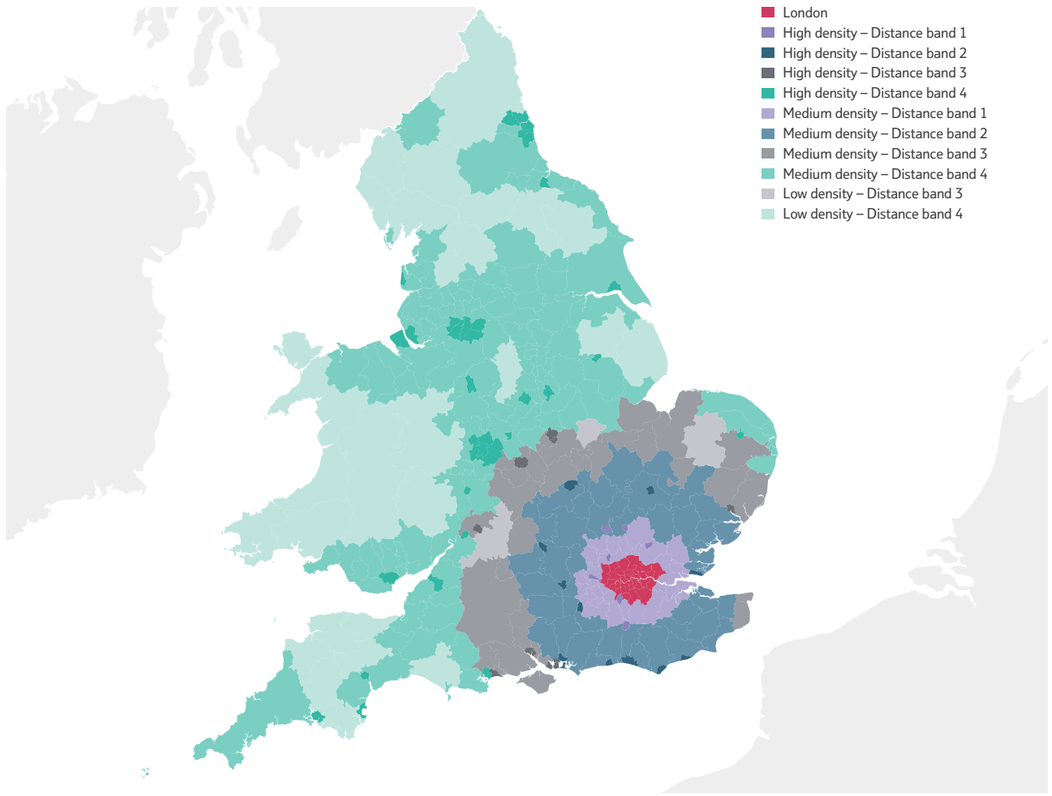
28 local authorities including: Northumberland, Copeland, Herefordshire, Shropshire, South Lakeland, North Devon, West Dorset, West Somerset, Eden, Boston, Ceredigion, Pembrokeshire, Powys

This category is made up of the most rural locations far from London (and in many cases far from any major cities at all), primarily in Wales and the Welsh Borders, the North, and the South West. In these remote, rural and coastal areas, the percentage of resident workers who work at home is higher than anywhere else, though again agriculture may explain this. Interestingly, these areas do benefit from relatively high availability of speeds above 70 Mbit/s – only in London is the share higher.

Resident workforce	Employees	Home workers	London workers
1,282,832	1,229,003	18.2%	0.5%

All the zone types are mapped in Figure 6.

FIGURE 6: Mapping of zones used in Cebr spatial model



Model scenarios and results

The central parameter of the model is the implied cost of digital commuting. This cost will heavily influence individuals' decisions about where to live, where to work, and whether to mainly commute into work or work from home.

Full fibre will make working remotely easier – thereby reducing the non-monetary costs for workers of being located away from their co-workers, managers or teams.

A lower cost of digital commuting is likely to drive more people to work from home and change their residence and employment location decisions, as proximity to existing major employment centres becomes less important.

This section presents baseline results and results based on different rates of change in the future.

Baseline: explaining observed changes from 2011-2019

The spatial model is based on 2001 and 2011 Census data, as commuting patterns between local authorities are central to it. In order to capture changes in patterns of working from home that have occurred since 2011, we reviewed data from the Quarterly Labour Force Survey[46]. This suggested that the share of workers who mainly worked from home increased between 2011 and 2019 by 1.3 percentage points from 12.7% to 14.0%[47].

In the spatial model, a **£1.45 fall in the cost of digital commuting** (relative to the value calculated within the model in the calibration to 2011 data) is required to increase the work-from-home share by 1.3 percentage points. Therefore we treat this change as our baseline.

Continuation of trend in digital commuting costs

The £1.45 fall in the cost of digital commuting which we estimate occurred between 2011 and 2019 equates to an annual decrease of just over £0.18. Were this trend to continue from 2019 to 2033, there would be a **total fall in digital commuting costs of approximately £4.00**.

This continuation of trends can be seen as a 'do minimum' case – where digital infrastructure improves incrementally, and there is a smaller increase in home working primarily as a result of changing work patterns and culture. In effect, this is what we would expect to happen without further investment in digital infrastructure.

Acceleration of improvement in digital commuting costs

As the basis for a faster fall in digital commuting costs, we look at what our model estimates occurred between the Census years of 2001 and 2011. An increase in digital commuting costs of slightly under £3.00 is needed to produce work-from-home levels similar to those seen in 2001, so we estimate that digital commuting costs fell by this much between the Census years. Were a similar rate of change to occur from 2019 to 2033, there would be a **total fall in digital commuting cost of £5.50**.

This can be seen as the outcome of markedly improved digital connectivity, where full fibre underpins a significant escalation in home working trends and accompanying spatial redistribution. This represents the potential impact of Openreach and others delivering an accelerated full fibre deployment across the country.

Summary of results by scenario

This section shows the results of the spatial model:

- as calibrated to 2011 Census data, i.e. the observed results on which the model is based;
- for the 2019 baseline, reflecting Quarterly Labour Force Survey data to the present day;
- for a fall in digital commuting costs implied by trends continuing to 2033;
- for a fall in digital commuting costs implied by trends accelerating to 2033.

Results are based on changes to the 2011 Census data, so in all scenarios there are roughly 24.5m workers – these results provide a view of how the model suggests those workers would have behaved given a different cost of digital commuting.

Table 6 shows results broken down by the 11 archetype areas used in the model. On continued trends in digital commuting costs, approximately 630,000 more people than today are expected to work from home, with the work from home share increasing by 2.6% to 14.5%.

For the accelerated trend scenario, over one million additional people work from home, with 16.2% of workers now doing so. Table 6 suggests that another 400,000 people could work from home under an accelerated trend model where full fibre is deployed compared to the continued trend scenario.

The residential choices in an accelerated trend show a clear urban/rural split, with over 75,000 people moving out of London and almost 200,000 people choosing to move out

of the four high density areas and into medium and low density areas across the country. This will equate to over 270,000 people being enabled to move away from high density areas and choosing to live in more suburban and rural areas.

Beyond this, over 90,000 people will choose to work in rural areas under an accelerated scenario.

TABLE 6: Results of spatial model by scenario, archetype area breakdown

				Continued trend		Accelerated trend	
		Calibrated model	2019 baseline	Results	Relative to baseline	Results	Relative to baseline
Commuting	Mainly work from home	2,587,466	2,901,285	3,531,601	630,316	3,958,736	1,057,451
	Mainly work from employer site	21,815,613	21,501,794	20,871,478	-630,316	20,444,343	-1,057,451
% working from home		10.6%	11.9%	14.5%	2.6%	16.2%	4.3%
Workplace	London	3,407,152	3,379,610	3,324,515	-55,095	3,287,347	-92,262
	High density – Dist band 1	701,835	702,056	702,338	282	702,405	349
	High density – Dist band 2	1,032,478	1,034,434	1,038,260	3,826	1,040,775	6,341
	High density – Dist band 3	1,189,937	1,196,812	1,210,489	13,677	1,219,657	22,846
	High density – Dist band 4	4,106,311	4,086,195	4,048,202	-37,993	4,024,279	-61,916
	Medium density – Dist band 1	1,630,913	1,627,508	1,620,374	-7,135	1,615,316	-12,192
	Medium density – Dist band 2	2,324,360	2,336,524	2,360,030	23,506	2,375,256	38,732
	Medium density – Dist band 3	2,062,145	2,083,989	2,127,274	43,285	2,156,156	72,167
	Medium density – Dist band 4	6,716,412	6,696,526	6,656,537	-39,989	6,629,433	-67,093
	Low density – Dist band 3	230,050	237,550	252,524	14,974	262,600	25,050
	Low density – Dist band 4	1,001,487	1,021,875	1,062,536	40,661	1,089,853	67,979
Residential	London	3,732,497	3,710,323	3,665,432	-44,891	3,634,742	-75,581
	High density – Dist band 1	318,239	317,752	316,706	-1,047	315,945	-1,807
	High density – Dist band 2	821,884	815,794	803,516	-12,278	795,163	-20,630
	High density – Dist band 3	666,584	662,891	655,393	-7,498	650,252	-12,640
	High density – Dist band 4	3,454,199	3,405,518	3,308,834	-96,683	3,244,145	-161,373
	Medium density – Dist band 1	1,870,469	1,869,230	1,866,304	-2,926	1,863,990	-5,239
	Medium density – Dist band 2	2,732,298	2,754,101	2,797,446	43,345	2,826,471	72,370
	Medium density – Dist band 3	1,878,726	1,888,854	1,908,789	19,935	1,921,985	33,131
	Medium density – Dist band 4	7,515,119	7,520,251	7,528,763	8,512	7,533,170	12,919
	Low density – Dist band 3	119,753	123,963	132,687	8,723	138,802	14,838
	Low density – Dist band 4	1,293,312	1,334,403	1,419,210	84,807	1,478,414	144,010

Table 7 shows the same results at the level of regions, including metropolitan/non-metropolitan splits for the northern regions and the West Midlands, which contain large urban conurbations, where results are very different to those for the suburban and rural regions around them.[48]

Considering results at the regional level shows a pattern in line with the archetype area analysis. London and most of the metro areas see residents moving away, into the non-metropolitan parts of the regions, and more rural regions like Wales and the East of England. In all, the model shows over 170,000 people move out of London and metro regions in the West Midlands and the North into more rural and suburban areas.

TABLE 7: Results of spatial model by scenario, regional breakdown including metropolitan/non-metropolitan splits

				Continued trend		Accelerated trend	
		Calibrated model	2019 baseline	Results	Relative to baseline	Results	Relative to baseline
Commuting	Mainly work from home	2,587,466	2,901,285	3,531,601	630,316	3,958,736	1,057,451
	Mainly work from employer site	21,815,613	21,501,794	20,871,478	-630,316	20,444,343	-1,057,451
% working from home		10.6%	11.9%	14.5%	2.6%	16.2%	4.3%
Workplace	North East metro	641,059	638,220	632,801	-5,418	629,345	-8,875
	North East non-metro	373,314	374,476	376,780	2,304	378,318	3,842
	North West metro	1,715,462	1,708,287	1,694,504	-13,782	1,685,644	-22,643
	North West non-metro	1,130,019	1,129,985	1,129,902	-83	1,129,836	-149
	Yorkshire & Humber metro	1,378,267	1,374,186	1,365,980	-8,206	1,360,418	-13,768
	Yorkshire & Humber non-metro	674,598	674,684	674,898	214	675,075	391
	East Midlands	2,026,145	2,030,795	2,040,138	9,343	2,046,471	15,676
	West Midlands metro	1,254,495	1,252,542	1,249,096	-3,446	1,247,123	-5,419
	West Midlands non-metro	1,158,305	1,162,183	1,169,955	7,771	1,175,207	13,023
	East	2,869,246	2,879,749	2,900,200	20,451	2,913,569	33,821
	London	3,407,152	3,379,610	3,324,515	-55,095	3,287,347	-92,262
	South East	4,313,825	4,328,537	4,356,986	28,448	4,375,426	46,889
	South West	2,349,583	2,356,711	2,371,139	14,428	2,380,998	24,287
	Wales	1,111,609	1,113,114	1,116,186	3,072	1,118,303	5,188
Residential	North East metro	566,469	560,779	549,443	-11,336	541,832	-18,947
	North East non-metro	458,392	462,961	472,302	9,341	478,757	15,796
	North West metro	1,662,326	1,650,000	1,625,353	-24,647	1,608,733	-41,267
	North West non-metro	1,192,879	1,198,350	1,209,435	11,085	1,217,022	18,672
	Yorkshire & Humber metro	1,396,615	1,397,569	1,399,151	1,582	1,399,970	2,401
	Yorkshire & Humber non-metro	722,687	725,369	730,876	5,507	734,699	9,330
	East Midlands	1,945,564	1,947,733	1,952,110	4,377	1,955,093	7,360
	West Midlands metro	1,038,256	1,026,498	1,003,106	-23,391	987,426	-39,072
	West Midlands non-metro	1,253,866	1,260,162	1,273,061	12,899	1,281,996	21,835
	East	2,755,602	2,763,960	2,780,387	16,428	2,791,245	27,286
	London	3,732,497	3,710,323	3,665,432	-44,891	3,634,742	-75,581
	South East	4,186,407	4,196,698	4,216,648	19,949	4,229,615	32,917
	South West	2,284,671	2,288,077	2,295,225	7,148	2,300,303	12,227
	Wales	1,206,848	1,214,601	1,230,550	15,949	1,241,645	27,044

Overall, more people also choose to live and/or work in low density areas and areas further from London such as Wales and the rural North. This suggests that as physical proximity becomes less important, living in these locations will become more desirable.

The change in living patterns is generally speaking more drastic than the change in working patterns (e.g. nearly eight times as many people stop living in West Midlands metro – i.e. Birmingham – as stop working there) – this suggests that although some employment moves away from London and high density areas, many workers choose to stay employed in these locations whilst living more remotely and working from home. North West non-metro sees a negligible change in the number choosing to work there, but nearly 20,000 more people living there; these may represent for example people who continue being employed in Greater Manchester or Liverpool City Region (or other cities further afield), but choose to take advantage of remote working opportunities to live in a pleasant rural or coastal location.

Estimated Scottish and Northern Irish impacts

As discussed above, the inclusion of Scotland and Northern Ireland in this spatial model was not possible due to data limitations. Nevertheless, it is possible to infer the nature of the spatial impacts that may occur based on their characteristics and sizes.

Scotland contains a fairly densely populated metropolitan region (the Central Belt, containing about 70% of the country's population) and extensive sparsely populated areas. In this respect it is quite similar to Yorkshire and the Humber, to which it has a very similar population (about 5.3m): we therefore estimate that Scotland could also gain over 10,000 residents under an 'accelerated trend', and that Edinburgh and Glasgow would lose population whilst low-density locations like the Highlands and Islands would see new residents.

Northern Ireland is perhaps more similar to Wales, with some medium-sized cities and extensive rural areas. Scaling Welsh impacts for Northern Ireland's population[49], it could gain approximately 17,000 residents and see a small employment boost.

It is important to note that the rurality and density of both Scotland and Wales are not directly comparable to other areas of the UK, and that the figures above are rough estimates rather than the output of more detailed analysis. Ideally we would have a comprehensive model including the entirety of the UK, as this would fully capture all impacts driven by the UK's differing geography and place quality, and individuals' decisions about where to live. For instance, some of the people who choose to move away from cities into rural England or Wales may instead move to Scotland or Northern Ireland (and these may be matched by Scottish and Northern Irish workers making moves in the other direction).

Increased output from new home workers

As more people switch away from commuting towards increased working from home, it is possible that some of the time saved commuting will be spent working.

Based on the results of our spatial model, we attempt to conservatively estimate the GVA impact of these increased hours of work. We produced these estimates based on the following:

- within the spatial model, those who mainly work from home still commute to a place of employment one day per week, and those who mainly work from an employer site commute there four days per week – therefore on average, employees work from home rather than commuting three days per week, over a 45-week working year;
- the potential time saved is based on an average round-trip commute of 61 minutes[50]. We assume that on the three additional days that these workers are working from home, 50% of the commuting time saved is spent working. This equates to an additional 1.5 hours per working week or 68.7 hours (1.8 weeks' worth of work[51]) per working year;
- the numbers of new home workers are based on the 'accelerated trend' scenario for rollout, with figures for future years adjusted to account for the projected growth of the working age population – this is why the numbers of additional home workers anticipated once rollout is complete are higher than those from the results of the spatial model above[52];
- the value of additional hours worked is based on Cebr forecasts for GVA per hour;

- results are produced for 2025 and 2033 rollout – the full potential benefits are realised once rollout has been completed, with partial benefits realised in earlier years.

Results are summarised in Table 8: Estimated number of new home workers relative to 2019 baseline from Cebr spatial model and GVA impact (2017 £ million), 2033, 2030, 2028, and 2025 rollout. Impacts are identical for 2033 and after for rollout in all years – in any case the full benefits are realised by 2033. An earlier rollout delivers significantly greater benefits in 2025 however, with more than twice as many additional people mainly working from home relative to 2033 rollout. The boost to GVA is thus £2.7 billion rather than £1.2 billion.

TABLE 8: Estimated number of new home workers relative to 2019 baseline from Cebr spatial model and GVA impact (2017 £ million), 2033, 2030, 2028, and 2025 rollout

		2025	2028	2030	2033	2038
2033 rollout	New home workers	466,833	699,303	853,463	1,087,074	1,088,724
	GVA (£ million)	£1,157	£1,774	£2,196	£2,860	£2,981
2030 rollout	New home workers	594,151	890,023	1,086,226	1,087,074	1,088,724
	GVA (£ million)	£1,473	£2,258	£2,795	£2,860	£2,981
2028 rollout	New home workers	726,185	1,087,805	1,086,226	1,087,074	1,088,724
	GVA (£ million)	£1,800	£2,759	£2,795	£2,860	£2,981
2025 rollout	New home workers	1,089,277	1,087,805	1,086,226	1,087,074	1,088,724
	GVA (£ million)	£2,700	£2,759	£2,795	£2,860	£2,981

In effect, and as per the labour productivity impacts, an earlier rollout accelerates the pace of change, allowing full social and economic impacts of spatial reallocation to be realised sooner.

There are reasons to believe these results may be conservative – for instance:

- those who choose to work from home are likely to be those with relatively long commutes, as avoiding those is relatively more desirable – therefore the amount of time freed up may be larger than national average commuting times suggest;
- physically commuting can be tiring and stressful – doing less of it could make workers more productive during much of the time they work;
- GVA per hour is likely to be higher than the national average for digital commuters, due to the knowledge-intensive nature of jobs in which it is most feasible;
- the spatial model is limited in its geographic scope – impacts from Scottish and Northern Irish workers could increase total benefits;
- some larger corporates have increasingly aimed to encourage home working to allow for reductions in office space and desk count. If this trend increases, catalysed by widespread availability of full fibre, 'compulsory' home working could become more widespread.

We have chosen not to assume that all of the commuting time saved is spent working, as this would not be realistic. However, the *leisure* time people gain will affect the nature of demand, for instance if remote workers choose to spend time and money on leisure activities in their area.

Our spatial model anticipates that more people will live in rural areas and regions distant from London. This spending could boost areas which traditionally perform less well economically. For instance coastal areas in Wales and small, post-industrial towns or highly rural areas in the North of England could see increased retail and leisure demands. Sparsely-populated areas would see increased demands on public services like health and education, which could make provision of these services more efficient in areas which sometimes struggle to maintain them. The policy implications and potentially very significant social benefits of this spatial reallocation are discussed in the final chapter of this report.

Environmental benefits of increased working from home

The reduction in commuting trips brought about by increased work from home can be expected to deliver environmental benefits as there will be fewer cars on the roads.

With over a million more people in the UK mainly working from home, as indicated by the 'accelerated trend' results from our spatial model, Cebr estimates that each year there will be:

- **300 million commuting trips** fewer, of which nearly 200 million are by car;
- **three billion kilometres** fewer travelled by car;
- **360,000 tonnes** fewer of carbon dioxide emiited.

This is based on:

- Each of the 1,087,074 additional home workers in 2033 works from home instead of commuting to a place of employment 135 days a year (three additional days worked from home per week, 45 working weeks in a year) – therefore they each commute to or from work 270 times fewer per year;
- 63.7% of these journeys would have been by car[53] and their average distance would have been 15.9 kilometres[54];
- Average CO_2 emissions per kilometre of 121.3g[55].

Workforce impacts

Key findings

01 Nationwide full fibre deployment could bring **over 500,000 new workers into the workforce** through allowing them to work from home by 2038. In total, over 700,000 people could increase their working hours;

02 These increases in working hours could have a GVA impact of over £15 billion annually;

03 We estimate that over 450,000 people who are currently carers could be enabled to enter, or reenter the workforce as a result of full fibre, or to increase their working hours;

04 Almost 150,000 over-65s could continue to work, or could set up their own business;

05 Over 125,000 women with dependent children could be supported to re-enter the workforce[56].

Introduction

The spatial model estimates reallocation of existing workers between workplace locations, residence locations, and commuting patterns.

It does not however estimate *labour supply* impacts which change the *size* of the workforce.There is clear potential for enhanced digital infrastructure to bring new workers into the labour force or allow those already in it to significantly increase their hours.

We therefore consider the labour supply responses and resulting economic impacts that could arise among groups which currently find it difficult to access the labour market. The methodologies for estimating these responses among carers, older generations, and parents are outlined below, with employment and GVA impacts summarised in the final section.

We have not directly assessed the extent to which new business creation, or innovation within existing businesses, will affect the size of the labour force, as the evidence on these impacts is mixed. Instead we focus on how radically improved universal connectivity could provide new employment opportunities for different parts of society.

Enabling carers to work remotely

The 2011 Census found 6.5 million people provide some level of unpaid care[57], defined as *'looking after, giving help or support to family members, friends, neighbours or others because of long-term physical or mental ill-health/disability, or problems related to old age'*. Therefore this does not include most childcare.

A key driver of the number of carers is the UK's ageing population. Many people caring for elderly or disabled relatives face constraints on the nature and amount of paid work they are able to undertake, as they need to be present for lengthy periods or at particular times of day, or at least close at hand if urgent assistance is needed, preventing regular travel to a place of employment.

It is therefore unsurprising that carers are significantly less likely to be in full time employment and more likely to be economically inactive than the general population.[58]

By making it easier to do certain jobs from anywhere, full fibre will expand the work opportunities open to carers. It may also enable some carers to attend a workplace regularly by allowing better 'remote care'. Some of these further impacts will be assessed in a future report.

The potential economic opportunities for those with caring responsibilities arising from full fibre, come through:

- more hours worked by those who are currently employed alongside their caring responsibilities, but are unable to work as much as they would like;
- entry into the labour force by those who are currently unable to work due to caring responsibilities, but would like to do so.

- To quantify the potential economic impact of flexible, remote working by carers as a result of full fibre rollout, Cebr has applied the following methodology:
- analysis of 2011 Census data concerning the number, ages, and geographical distribution of the UK's carers;
- identification of a plausible, conservative scenario regarding additional labour supply by carers which could result from the deployment of full fibre;
- valuation of the impacts arising from these scenarios according to additional hours worked and forecast national GVA per hour.

Census data on the number of residents providing unpaid care by local authority in break down the total number of unpaid carers by UK region. There is also data on the age profile of those who provide unpaid care, which we have used to estimate the number of working-age carers. We assume that only these people are 'in scope' for increased work as a result of full fibre rollout – in this way we can avoid including those too young to work or those who are beyond retirement age.[59]

TABLE 9: Unpaid carers by UK region; estimated unpaid carers of working age

Region	Total unpaid carers	Aged 25-64 (estimated)
North East	286,351	204,356
North West	781,972	552,821
Yorkshire and The Humber	551,341	391,829
East Midlands	490,249	346,049
West Midlands	614,888	430,896
East	597,591	416,637
South East	847,353	593,136
London	689,973	506,576
South West	570,298	387,514
Wales	370,230	254,082
Scotland	492,231	344,575
Northern Ireland	213,980	149,792
UK	**6,506,457**	**4,578,262**

Census 2011, provision of unpaid care; provision of unpaid care by age

We consider a scenario in which 10% of these carers work an extra 10 hours per week on average (equivalent to each carer working an hour more per week). The impacts are annualised[60] and valued according to Cebr forecasts for GVA per hour, to give the impact on total economic output.

For the purposes of the overall employment impacts, we assume that 50% of the carers who work additional hours are new to the workforce – i.e. the other 50% are people who work already but are able to increase their hours.

We do not assume growth over time in the number of working-age carers. Though the UK has an ageing population, and care demands are likely to grow as a result, the expected relative stagnation of the *working-age* population means that the number of carers in this bracket may not change significantly, with more care being provided by those who are no longer working age.

Precisely estimating the opportunities carers can realise from full fibre rollout would require considerably more detailed study. For instance extensive survey work would be needed to find out how many more hours they would be willing to work, and whether or not employers would be willing and able to accommodate more flexible and remote working.

For present purposes, we have adopted reasonably conservative assumptions about the proportion of carers who could enter work or increase their hours, and the number of additional hours they would each work. As the results of our analysis show, even on these assumptions the employment and GVA impacts are significant. This is a result of the sheer number of working-age carers in the UK. If full fibre unlocks greater labour force participation among them than our analysis assumes, the economic impacts could be even higher.

Enabling an ageing population to work later in life

Full fibre provides opportunities for greater labour supply not just among those caring for elderly people, but among older people themselves.

This could have a crucial bearing on future public finances, as an ageing population implies a lower ratio of workers paying taxes to retirees requiring pensions and social care. Between 2020 and 2041, the ratio of working-age people to people of state pension age is expected to fall sharply, from 3.47 to 2.65.[61] If more people can be enabled to work later into life and a higher proportion of those above state pension age continue to work and pay taxes, the ratio of workers to retirees will fall more slowly, reducing future fiscal challenges.

In 2018, 10.2% of the UK's over-65s were in work – just under 1.2 million people.[62] This cohort of workers has a number of interesting features:

- propensity to work at home rises with age – 38.3% of workers aged 65 or over use home as a workplace, compared to 18.3% of those aged 50-64, 12.3% of those aged 25-49, and 5.1% of those aged 16-24[63];
- this suggests there were approximately 450,000 workers aged over 65 and using home as a workplace in 2018;
- they are relatively likely to work part-time, with 57.3% of them employed on this basis;
- they tend to be more highly-skilled – they are 20% more likely than workers aged 16-64 to be employed in professional, scientific and technical activities.[64]

The marked increase in tendency to work from home among workers aged 65 and older suggests that they value the benefits of home working particularly highly and would be very receptive to changes which make doing so easier. As older generations are less likely to be 'digital natives', their employers may need to take steps to ensure they have the required skills to work productively from home. If resources were available for the self-employed to develop these skills, this would also help the over-65s to take opportunities presented to them by full fibre.

Table 10 considers the regional picture. Those regions in which older people are relatively strongly represented will stand to benefit the most from increased workforce participation among this group. This is clearly the case in the South West and Wales above all, and to a lesser extent in regions like the North East and East. London and Northern Ireland have relatively young populations, so this opportunity is relatively less important for them.

TABLE 10: Population over 65 relative to overall population, UK regions

Region	% of UK population (over 65s)	% of UK population (all)	% of over 65s / % of all population
North East	4.3%	4.0%	1.07%
North West	11.1%	11.0%	1.01%
Yorkshire and The Humber	8.4%	8.2%	1.01%
East Midlands	7.6%	7.2%	1.05%
West Midlands	9.0%	8.9%	1.01%
East	10.0%	9.3%	1.07%
South East	14.5%	13.7%	1.05%
London	8.7%	13.4%	0.65%
South West	10.1%	8.4%	1.20%
Wales	5.4%	4.7%	1.13%
Scotland	8.4%	8.2%	1.03%
Northern Ireland	2.5%	2.8%	0.89%

In estimating of the potential impact of increased remote working among older people, we assume that:

- full fibre rollout increases the number of over-65s working from home by 25% (i.e. by approximately 110,000 in 2018, when there were roughly 450,000 older home workers);
- figures for future years are adjusted in line with the expected growth of the population aged 65-74[65];
- these people work an average of 15 hours per week in a 45-week working year;
- these additional hours are valued according to Cebr forecasts for GVA per hour.

This approach is quite conservative for a number of reasons:

- there are ways other than those considered above in which labour supply by older workers could be increased through full fibre rollout:
- those who currently take early retirement could instead work up to the State Pension Age – as these people are under 65 they are not counted in this methodology;
- those over 65 who currently work part-time could increase their hours with greater freedom to work remotely – for instance by spending a day working at home in addition to days spent in an office;
- the 'new' workers might be full-time rather than part-time;
- the GVA per hour produced by these workers may be above the national average, owing to the accumulated experience of older workers, and the likelihood that home workers will be in knowledge-intensive occupations.

Bringing forward parents' return to work

A further group which stands to benefit from greater opportunities for remote working enabled by full fibre are parents of dependent children, who may otherwise struggle to balance work with parenting responsibilities and therefore may choose to leave the workforce.

We focus on the potential for employment to increase among women with dependent children, as their employment rate is markedly lower than that for men – as highlighted in Table 11.[66] Among those with dependent children, the female employment rate is nearly 20% lower than the male employment rate.

Greater flexible and remote working promoted by increased availability of full fibre could start to close this gap. The potential benefits are very large – more than 1.7 million women with dependent children were not employed in 2018, and approximately 1.2 million more would be employed if their employment rate matched that of men with dependent children.

TABLE 11: Employment rates for men and women with and without dependent children

Group	Employment rate (%)
Men with dependent children	93.1
Men without dependent children	73.7
Women with dependent children	74.0
Women without dependent children	69.7

It would however be unrealistic to assume that the gap can be closed altogether – not all workers can benefit from remote, flexible working, even with full fibre, and for many parents not working is a matter of choice.

We therefore estimate impacts using a cautious 10% closing of the gap – implying that the employment rate of women with dependent children increases from 74.0% to 75.9%. In the absence of detailed analysis or survey work to inform this assumption, we choose to examine the impact of this very conservative change – which as we will demonstrate is still substantial.

We also assume:

- the total number of women with dependent children grows in line with the number of women in the UK aged 20-44 as projected by the ONS;[67]
- the mothers returning to the workforce tend to do so on a part-time basis, working on average 15 hours per week in a 45-week working year;
- these hours of work are valued according to Cebr forecasts for GVA per hour.

These impacts could be increased by existing part-time workers increasing their hours as a result of improved flexibility, those returning to the workforce doing so for more than 15 hours per week, or a larger proportion closing of the employment gap.

Regional data on the distribution of working-age parents is not available, so we assume that employment impacts here are distributed in line with Cebr's forecasts of employment by region.

Summary of workforce impacts

As with the impacts of increased home working, we consider impacts of rollout in 2033, 2030, 2028, and 2025, and assume that full benefits materialise upon completion of the rollout, with only partial benefits emerging before then.

Table 12, Table 13, Table 14, and Table 15 show impacts for rollout completed in 2033, 2030, 2028, and 2025 respectively. The difference between 'workers affected' and 'of which new employees' in the total workforce impacts sections is due to the assumption that 50% of carers are new to the workforce and 50% are in the workforce already and increase their hours – those in the latter category form part of the workforce impacts but not the new employees.

Unlike the productivity-based impacts, workforce benefits in 2033 and 2038 are the same with rollout in any year. 2025 rollout delivers substantially greater workforce impacts in that year. The GVA premium to rollout in 2025 rather than 2033 is over £7 billion in 2025.

In any case, on completion of rollout 700,000 workers benefit either by being able to increase their hours or enter the workforce and the uplift in GVA is in excess of £10 billion, with employment roughly 500,000 higher.

A further potential effect which could benefit any of these groups is improved *job matching* – a greater ability to work flexibly from anywhere would expand the range of jobs available, which may boost their earnings depending on their skill set and how well they are currently able to utilise it. This would benefit those currently in the labour force as well as those entering or re-entering it as a result of full fibre rollout. Furthermore, these groups could more easily take advantage of remote learning opportunities as well as or instead of work, boosting their productivity and earnings in the future.

TABLE 12: Summary of estimated workforce impacts by category for 2033 rollout, values in 2017 £

		2025	2028	2030	2033	2038
Forecast GVA per hour		£36.09	£36.93	£37.46	£38.31	£39.86
Carers	Workers affected	196,211	294,317	359,721	457,826	457,826
	Additional hours worked/year	88,295,060	132,442,590	161,874,277	206,021,807	206,021,807
	GVA impact (£ million)	£3,187	£4,891	£6,063	£7,893	£8,212
Older	Workers affected	51,746	83,198	107,011	143,658	146,431
	Additional hours worked/year	34,928,732	56,158,774	72,232,566	96,969,184	98,840,728
	GVA impact (£ million)	£1,261	£2,074	£2,706	£3,715	£3,940
Parents	Workers affected	53,969	80,701	98,711	125,926	125,317
	Additional hours worked/year	36,429,270	54,473,069	66,629,954	85,000,248	84,588,855
	GVA impact (£ million)	£1,315	£2,012	£2,496	£3,256	£3,372
Total workforce impacts	Workers affected	301,927	458,216	565,443	727,411	729,574
	Of which new employees	203,821	311,057	385,583	498,497	500,661
	Additional hours worked/year	159,653,062	243,074,432	300,736,797	387,991,240	389,451,390
	GVA impact (£ million)	£5,762	£8,977	£11,265	£14,864	£15,524

TABLE 13: summary of estimated workforce impacts by category for 2030 rollout, values in 2017 £

		2025	2028	2030	2033	2038
Forecast GVA per hour		£36.09	£36.93	£37.46	£38.31	£39.86
Carers	Workers affected	249,723	374,585	457,826	457,826	457,826
	Additional hours worked/year	112,375,531	168,563,297	206,021,807	206,021,807	206,021,807
	GVA impact (£ million)	£4,056	£6,225	£7,717	£7,893	£8,212
Older	Workers affected	65,859	105,889	136,196	143,658	146,431
	Additional hours worked/year	44,454,750	71,474,803	91,932,357	96,969,184	98,840,728
	GVA impact (£ million)	£1,604	£2,640	£3,444	£3,715	£3,940
Parents	Workers affected	68,688	102,710	125,632	125,926	125,317
	Additional hours worked/year	46,364,525	69,329,360	84,801,760	85,000,248	84,588,855
	GVA impact (£ million)	£1,673	£2,560	£3,177	£3,256	£3,372
Total workforce impacts	Workers affected	384,270	583,184	719,655	727,411	729,574
	Of which new employees	259,409	395,891	490,741	498,497	500,661
	Additional hours worked/year	203,194,807	309,367,460	382,755,923	387,991,240	389,451,390
	GVA impact (£ million)	£7,334	£11,426	£14,337	£14,864	£15,524

TABLE 14: Summary of estimated workforce impacts by category for 2028 rollout, values in 2017 £

		2025	2028	2030	2033	2038
Forecast GVA per hour		£36.09	£36.93	£37.46	£38.31	£39.86
Carers	Workers affected	305,217	457,826	457,826	457,826	457,826
	Additional hours worked/year	137,347,871	206,021,807	206,021,807	206,021,807	206,021,807
	GVA impact (£ million)	£4,957	£7,609	£7,717	£7,893	£8,212
Older	Workers affected	80,494	129,419	136,196	143,658	146,431
	Additional hours worked/year	54,333,583	87,358,092	91,932,357	96,969,184	98,840,728
	GVA impact (£ million)	£1,961	£3,226	£3,444	£3,715	£3,940
Parents	Workers affected	83,952	125,535	125,632	125,926	125,317
	Additional hours worked/year	56,667,753	84,735,884	84,801,760	85,000,248	84,588,855
	GVA impact (£ million)	£2,045	£3,129	£3,177	£3,256	£3,372
Total workforce impacts	Workers affected	469,664	712,780	719,655	727,411	729,574
	Of which new employees	317,055	483,867	490,741	498,497	500,661
	Additional hours worked/year	248,349,208	378,115,784	382,755,923	387,991,240	389,451,390
	GVA impact (£ million)	£8,963	£13,965	£14,337	£14,864	£15,524

TABLE 15: Summary of estimated workforce impacts by category for 2025 rollout, values in 2017 £

		2025	2028	2030	2033	2038
Forecast GVA per hour		£36.09	£36.93	£37.46	£38.31	£39.86
Carers	Workers affected	457,826	457,826	457,826	457,826	457,826
	Additional hours worked/year	206,021,807	206,021,807	206,021,807	206,021,807	206,021,807
	GVA impact (£ million)	£7,436	£7,609	£7,717	£7,893	£8,212
Older	Workers affected	120,741	129,419	136,196	143,658	146,431
	Additional hours worked/year	81,500,375	87,358,092	91,932,357	96,969,184	98,840,728
	GVA impact (£ million)	£2,942	£3,226	£3,444	£3,715	£3,940
Parents	Workers affected	125,928	125,535	125,632	125,926	125,317
	Additional hours worked/year	85,001,630	84,735,884	84,801,760	85,000,248	84,588,855
	GVA impact (£ million)	£3,068	£3,129	£3,177	£3,256	£3,372
Total workforce impacts	Workers affected	704,496	712,780	719,655	727,411	729,574
	Of which new employees	475,583	483,867	490,741	498,497	500,661
	Additional hours worked/year	372,523,812	378,115,784	382,755,923	387,991,240	389,451,390
	GVA impact (£ million)	£13,445	£13,965	£14,337	£14,864	£15,524

Wider Benefits and Implications

Wider social benefits of full fibre

There are a number of potentially significant but non-monetised effects that are not captured in the quantification of economic benefits in our analysis of productivity, spatial and workforce effects.

The quality of digital services will be transformed by access to full fibre and this will have a number of benefits for individual users. These include:

- improved public services, including potential for remote health consultations and education courses;
- leisure activities, including new modes of consuming culture and entertainment through virtual and augmented reality devices;
- an improved home environment, enabled through new IOT applications and devices;
- greater interaction amongst people through improved telecommunications and social networking platforms;
- improved reliable access to information, enabling people to make more informed decisions about their lives, e.g. being able to consider a wider range of goods and services at more competitive prices prior to purchase, opportunities for leisure time activities outside the home and so on:
  - these will be particularly valuable in more remote locations where digital connectivity is currently less well developed and physically accessing services relatively difficult – research into the impacts of superfast rollout in Cornwall[68] found that this improved connectivity changed the way residents looked for work (25% of household survey respondents said superfast had changed their job search activity), accessed goods and services (70% agreed it had helped with this), and it increased the proportion of people using the Internet to access a range of Government and public services.

The impact of greater opportunities for remote working will enable major changes in how work is done. This report has quantified some of the economic benefits which could be delivered as a result of these changes, but there will also be intangible effects such as improved job satisfaction and reductions in the stress of commuting that should also be considered.

These may indirectly contribute to broader economic benefits. More relaxed workers may be more productive and willing to do more work. Digital connectivity also has implications for *when* work is done. Previous studies have suggested that there is a small, but positive correlation between remote working and productivity, employee retention and commitment. Remote working will also enable many types of work to be undertaken outside standard working hours, which will help people more easily find a work life balance that suits their overall circumstances.

An important social benefit of reduced travel to work is likely to be additional leisure time, which includes opportunities for spending more time with family or exercising, both of which will have wider benefits.

As daily travel to work in offices for standard working hours becomes less typical, proximity to the office may become a less important factor in people's residential preferences. The corollary of this is that cost and quality of life factors are likely to become more important factors in people's choice of residential location. This will free up options that offer higher quality of life but would have previously been ruled out on grounds of distance or inaccessibility. Benefits from this include:

- workers being able to live in larger houses in more pleasant locations;
- regeneration of struggling coastal communities and left behind towns;
- more socially inclusive communities through a greater spread of prosperity across different types of location.

Wider policy implications

Deploying digital infrastructure can also form part of strategies to promote a more socially cohesive and fair society, through helping ensure that particular groups are not excluded from social and economic opportunities. It could also serve to reduce gaps in opportunities for people living in different places, both at the local and regional level.

The urban/rural divide in quality of provision and speeds available is such an issue – in urban areas, spreading fixed costs between large numbers of people is easier, however equity objectives demand provision in rural areas too.

Moreover the results of our spatial analysis confirm that nationwide full fibre rollout can be expected to bring about changes in where and how people live and work. Such significant changes would have major impacts, including on the main policy challenges faced by the UK – helping to solve some whilst creating potential challenges elsewhere. In this section we consider a range of wider complementary policies, in areas such as housing, transport and regional strategy.

The extent to which the higher economic impacts set out previously in this report can be achieved could also depend on the extent to which some of these complimentary policy measures are taken. In our view, investments in transport and skills will help to support these higher impact forecasts and should also be undertaken by Government.

Housing affordability

The UK has an acute housing affordability problem. Measured by ratio of median house prices to earnings, this problem is concentrated in London (particular inner London) and cities around it like Cambridge and Oxford.[69] Cities like these are major employment centres for the sort of knowledge-intensive employment that in theory could suit greater remote working.

Given this picture, and the indications of the spatial modelling that a lower cost of digital commuting will lead to movements of employment and population away from London and other major population centres, the implications are clear. Full fibre deployment could ease pressures in the UK housing market by supporting the movement of people away from the areas in which demand pressures are currently most severe and towards those in which housing markets are not overheating.

A movement of people into more sparsely-populated rural area and into coastal areas[70] could however generate house price pressures in these markets, pricing locals out and removing one of the reasons for people to move there. It is therefore crucial that policies are in place to ensure that housing supply in remote areas is able to meet new demands.

TABLE 16: Average ratios of median house price to median gross annual earnings by spatial model area archetype, with aggregations by distance bands and densities

Area archetype from spatial model	Average house price: earnings ratio
London	14.5
Medium density – distance band 1	11.6
High density – distance band 1	10.4
Medium density – distance band 2	9.9
High density – distance band 2	9.8
Low density – distance band 3	9.7
Medium density – distance band 3	8.6
Low density – distance band 4	7.6
High density – distance band 3	7.6
Medium density – distance band 4	6.4
High density – distance band 4	6.3
Distance band 1 (all)	11.3
Distance band 2 (all)	9.9
Distance band 3 (all)	8.5
Distance band 4 (all)	6.6
High density (all)	7.6
Medium density (all)	8.1
Low density (all)	7.8

Expanding supply in these places should in theory be easier than in densely-developed city centres – though new housing projects may encounter resistance where there are concerns that these will not be in keeping with the existing area or will put pressure on existing infrastructure or public services.

To address these issues, local and national government could ensure the planning process is streamlined, but also ensure housing development goes hand-in-hand with infrastructure (including mandating full fibre in all new builds) and public service provision so it does not detract from quality of life. One solution may be holistically-planned 'garden community' type settlements which combine quality, affordable housing with quality infrastructure and carefully planned public transport.

Transport infrastructure requirements

As working from home will increasingly be a substitute for physically commuting to a place of employment, full fibre will reduce total demand on the transport network with positive effects for congestion on roads, overcrowding on public transport, and rail capacity issues.

People will still need transport infrastructure to support their (less frequent) commutes, leisure travel, and business travel. Transport accessibility will therefore remain an important determinant of the desirability of different locations. A new spatial distribution of population and employment will also imply a change of emphasis in *where* transport infrastructure needs to be provided and therefore what types of investment are required.

There are a number of high-profile transport projects currently proposed, planned, or underway, largely focussing on getting people between major cities or into cities from their hinterlands:

- Crossrail 2 between central London and parts of its commuter belt;
- High Speed Two (HS2) between London, Birmingham, Manchester, and Leeds;
- Northern Powerhouse Rail (NPR) to connect the North's cities;
- the smart motorways programme along with other upgrades to the UK's strategic road network.

Increased levels of home working will not eradicate the need for these schemes, but it will interact with them. For instance, HS2 and NPR will reduce the cost of commuting to the UK's big cities, with countervailing effects; those with jobs in these cities planning to largely work from home will be able to live in more remote areas than would otherwise be possible, or they may choose to physically commute to work more often in response to lower transport costs.

A more dispersed economic geography will require an increased focus on transport investments of the sort that have not received as much attention in recent years, to serve new residents and employment in rural and coastal areas of the country, and those far from London.

In this context, the renewed political focus on improving local and inter-city transport links in the North is timely. The required investments might include:

- road capacity upgrades, to prevent congestion that might otherwise result;
- increased provision of rural bus services;
- upgrades to regional rail services to improve frequency and speed of connections to major hubs, for instance double-tracking or electrification;
- restoration of previously closed railways.

Interventions such as these can ensure that people who wish to move to more remote areas are not deterred from doing so by the prospect of poor transport connectivity, and are able to deliver the housing market and regional rebalancing benefits previously discussed.

Transport schemes in remote areas may fail conventional cost-benefit analyses; government should incorporate the expected dynamic effects of the wider opportunities for local economic development and broader policy objectives set out here – this will require a more visionary approach to case making.

Other policy requirements

The impact of full fibre is likely to be most significant in those areas which currently face the greatest challenges of digital and physical connectivity, namely rural areas. This is backed up by the outputs of our spatial model.

Programmes to improve digital skills should therefore have a particularly strong focus on rural areas, where these skills may currently be less prevalent, in order to make sure these communities can fully realise the opportunities of radically improved connectivity.

One approach to realising social and economic opportunities in these areas is the promotion of rural digital hubs, which have been successfully implemented elsewhere. These are dedicated spaces designed to provide business and community facilities – e.g. office/co-working space, business mentoring, and digital training.[71]

Remote workers and entrepreneurs could benefit from co-working, meeting, and networking spaces, whilst existing residents could gain the skills needed to fully benefit from the potential social and economic advantages delivered by improved connectivity.

The privately-funded Ludgate Hub in Ireland provided a gigabit connection and drove business opportunities in the Skibbereen area on Ireland's rural south-west coast, for instance by hosting co-working companies and helping local businesses to start trading online. Residents also benefitted from digital training including coding classes for the younger generation. Hubs such as this can contribute to the 're-branding' of rural locations previously not seen as viable places to start or run a digital business.

In urban areas, initiatives like the RSA supported Cities of Learning programme envisage the whole city becoming a learning campus, recognising that, in the future, education will not stop at the school gate. Technology will power a revolution in lifelong learning where new skills will be acquired in a whole range of on and offline settings, not just in schools and colleges, and documented via recognised digital credentials that will be understood and valued by employers. As people adapt to a changing job market, we need the bandwidth that will fuel new ways for them to live and learn.[72]

TechUK recently proposed a series of initiatives, such as support for digital clusters and other forms of business support, which could also be used to enable as many businesses as possible to take full advantage of the opportunities offered by full fibre.[73]

Conclusion

Openreach's deployment of full fibre could transform economic and social opportunities for people across the UK. They have today published a blueprint for how they could accelerate their deployment to bring this into reality, and how Government could most effectively support the sector to do so.

Meeting the Government's ambitions for delivering this upgrade to existing infrastructure will be a massive civil engineering project, which will require joint working from industry, the Government and Ofcom. There are a number of different initiatives which the Government and Ofcom will need to deliver in order to make this possible.

This report demonstrates the possibilities which delivering full fibre could unlock. Full fibre connectivity could support a new wave of innovation and productivity gains – helping to underpin new growth across the country. The opportunity is there to be taken, and with the right support, the sector is ready to deliver.

Our evidence suggests that enabling increased home working opportunities could help to rebalance the economy and support rural economies across the country. It could also help to bring new people into the workforce.

To maximise these opportunities, there are a number of other actions the Government could take in order to support businesses in using digital technology. Ultimately though, it will be the individual choices of business owners and their employees which will determine the benefits which a upgraded digital infrastructure will present.

Annex: Analytical framework

There are a number of established analytical methods and economic theories that can help inform the estimation of the impacts of digital services on economic growth. These provide a useful means of identifying the range of likely benefits at a conceptual level and therefore represented a good basis for developing our quantified analysis. In summary:

- **Growth Accounting** offers a high level means of estimating the contribution of investment in full fibre connectivity. It involves estimating the impact on output resulting from the growth in the stock of capital represented by the network. Digital connectivity could also contribute to productivity[74] through providing a means of reducing the resource requirements of other sectors of the economy including transport, for which digital services may be a substitute. Additionally, there may be wider effects beyond direct users ("externalities") arising from productivity spillovers where sectors using digital services become more productive.
- **Social Cost Benefit Analysis** seeks to capture the 'willingness to pay' by consumers and firms for digital services, i.e. users of digital services, as a proxy for their economic value. In the context of this study, 'willingness to pay' would need to be interpreted broadly, i.e. in a long term sense, with consumers taking account of access to digital services in major decisions about where they live and work and whether they commute or work at home. Any 'externalities', which individuals aren't able to control themselves, should also be included to provide a fuller picture. These include effects, such as:
  - Agglomeration, giving rise to productivity benefits through knowledge spillover effects, better matching and sharing of resources arising from better connectivity (physical or virtual);
  - Wider benefits arising from people moving into more productive work or increasing their labour supply, e.g. higher tax revenues;
  - Improved competition in local markets;

Additional investment effects, including through any positive impacts of improved connectivity on investors' confidence in a location's future prospects (this reduces the risk perceived by the 'first mover' that can stymy investment in areas in need of regeneration).

New Economic Geography considers the factors that influence the location of industry and the size of cities and the implications these have for economic performance. Investment that lowers transport costs is recognised as one such influence and, since it is a more or less close substitute, investment in digital connectivity is another. Whereas transport facilitates the spatial concentration of employment in physical space, digital connectivity may in future enable similar benefits to be realised though 'virtual concentration' enabling the functional benefits of cities to be extended well beyond their physical boundaries.

- This would enable the positive impacts on productivity associated with 'agglomeration economies' to be realised without incurring the full costs of physical clustering (transport, housing etc.). The implication is that the 'market potential' usually associated with cities, and which forms the basis on which they attract investment, could be increased in other locations through digital connectivity, for example to smaller settlements that currently suffer from a lack of investment such as 'left behind' towns in the Midlands, North of England, and Wales.
- A further benefit of agglomeration is improved labour market 'matching' whereby larger labour market catchments enable deeper and more specialised pools of labour to develop. These are better able to meet the specialist requirements of firms in the cluster, making them and the cluster as a whole more productive and ultimately more competitive. By enabling skilled workers in remote locations to participate through home working or supporting longer distance, part time commuting, digital connectivity can help existing clusters grow virtually, making them more competitive. Alternatively, it could enable entirely new 'virtual clusters' to develop.
- **New Growth Economics** provides a framework for considering how policy can increase the long run rate of growth in output and labour productivity, by allowing for behavioural responses that can influence growth rates through driving up investment and innovation. To the extent that the full fibre rollout raises the productivity of private sector capital, private investment and growth will both increase. It therefore acts as a subsidy to capital accumulation. Of course the means of financing it has to be taken into account since additional taxes on the income from investment act in the opposite direction.
- Reducing the cost of innovation will increase the volume of innovative activity, raising the rate of technological change and therefore the growth rate. Also, if the size of the market is increased, this will encourage research and development and stimulate economic growth by offering the prospect of larger sales by innovators, thereby raising the reward to innovation. Another effect is that increased connectivity will lead to firms being exposed to greater competition (actual or potential), encouraging more efficient and better motivated management. Lower cost firms will increase their market share, which will increase the productivity of the economy and improve its competitiveness.
- **Gains from trade** arise as lower communication costs act as a proxy for trade liberalisation by reducing internal frictions. This enables the economy to specialise more strongly in its areas of comparative advantage, which is likely to lead to an overall expansion of the export sector and a contraction in sectors that compete with imports. This process has resulted in de-industrialisation in the UK and it is clear that the full realisation of these types of gains are strongly dependent on redeploying displaced workers and avoiding significant structural unemployment. Interestingly, the potential regional benefits of full fibre rollout could, as well as helping address earlier episodes of displacement, also significantly assist in redeploying any workers displaced through future industrial restructuring. To the extent that digital connectivity represents an effective substitute for transport, and high transport costs represent a barrier to trade, full fibre rollout could act as a means of reducing trade barriers. Empirical evidence indicates a significant positive effect on GDP.[75]

1 *More than a third of Europe's fastest-growing tech firms are in UK – study*, The Guardian, June 2019. Link.
2 *DCMS Sectors Economic Estimates 2017 (provisional): Gross Value Added*, Department for Digital, Culture, Media & Sport. Link.
3 DCMS, Future Telecoms Infrastructure Review. Link
4 There are currently c.33 million premises in the UK
5 *Future Telecoms Infrastructure Review: Call for Evidence – Contribution from Cisco*. Link.
6 Ofcom, *Wholesale Local Access Market Review: Statement – Volume 1, 2018*. Link.
7 *Cisco Visual Networking Index: Forecast and Trends. 2017–2022 White Paper*. Link.
8 Frontier Economics, for the National Infrastructure Commission. Link.
9 *National Infrastructure Assessment*, National Infrastructure Commission, July 2018, page 20.
10 Coverage availability from ThinkBroadband.com. Link
11 *Digital Economy and Society Index Report 2019 – Connectivity*, EU Commission. Link.
12 *BDUK Superfast Broadband Take-up Progress by UK Region – Q4 2018*, ISPreview, April 2019. Link.
13 *National Infrastructure Assessment*, National Infrastructure Commission, July 2018, pages 22-23.
14 Based on internal network analysis
15 Defined for present purposes as output per worker
16 *Evaluation of the Economic Impact and Public Value of the Superfast Broadband Programme: Final Report*, DCMS/Ipsos MORI, August 2018.
17 *Superfast Broadband Programme Evaluation, Annex B: Economic Impacts*, Ipsos MORI, July 2018, Appendix C: Supplementary Research on Large Increases in Available Download Speeds, pages 58-75. Link
18 Ipsos MORI also estimated a productivity impact for firms which did not relocate and saw available speeds increase by 500 Mbit/s or more, and found it to be 0%. They suggest that this is likely due to incumbent firms being crowded out by higher-productivity firms moving into their area. As this is a local rather than national effect, we focus on the 3% uplift estimated for 200 to 500 Mbit/s speed increases. While the 500Mbit/s increase will be more comparable to the introduction of full fibre networks, we have used the estimated impacts for lower speed increases to avoid distortion of our results by this effect.
19 *Picking up speed: Does ultrafast broadband increase firm productivity?*, Richard Fabling and Arthur Grimes, November 2016, Page 17. Link.
20 *The Skill Complementarity of Broadband Internet*, Anders Akerman, Ingvil Gaarder, and Magne Mogstad, November 2013, Page 20. Link.
21 *The Empirical Link Between Fibre-to-the-Premises Deployment and Employment: A Case Study in Canada*, Singer et al. (2015). Link.
22 *Evaluation of the Economic Impact and Public Value of the Superfast Broadband Programme: Final Report*, DCMS/Ipsos MORI, August 2018. DCMS/Ipsos MORI
23 *The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?*, Stephen D. Oliner and Daniel E. Sichel, Journal of Economic Perspectives, Volume 14, Number 4, 2000. Page 13.
24 i.e. if forecast growth in labour productivity for a particular year is 1.00%, it would be increased to 1.037%.
25 *The Historical Significance of Transport for Economic Growth and Productivity*, Nicholas Crafts and Timothy Leunig, London School of Economics, October 2005. Page 8.
26 *BT End 2018 on UK FTTP and Gfast Broadband Cover of 2.6m Premises*, ISPreview, January 2019. Link.
27 *The Economic Impact of Full Fibre Infrastructure in 100 UK Towns and Cities*, Regeneris Consulting for CityFibre, March 2019, Appendix B, pages 2-3. Link .
28 The value of a telecommunications network is proportional to the square of the number of connected users of the system; i.e. the value of the network rises exponentially as more users are connected to it and can engage in interactions reliant on full fibre with one another.
29 Based on growth of 2017 GVA per hour (£33.65) according to Cebr's productivity growth forecasts.
30 e.g. for rollout completed in 2025, benefits in 2022 are 3/6 of total potential benefits – rollout takes place in 2020, 2021, 2022, 2023, 2024, and 2025, so 2022 is the 3rd of 6 years of rollout. We do not make assumptions about what the potential ramp up in the annual build rate would be, as this is still not currently known.
31 2038 is the latest date which the CEBR model has forecast future labour productivity
32 Workforce effects are valued according to the 'policy-off' forecast of GVA per hour, so do not differ according to productivity scenario – the effect of adjusting per scenario would be very small in any case.
33 It should be noted that in summing the estimated effects, there is no double counting – the productivity impact concerns *output per hour of work* done for hours of work already forecast to be done, whereas the other impacts concern *additional hours of work* done.
34 It is only under scenarios B and C, where labour productivity growth increases once rollout is completed, that impacts diverge after rollout is completion.
35 These impacts are the same regardless of rollout year – in all cases rollout has been completed by 2033 and the full productivity impact therefore realised. It is only under scenarios B and C, where labour productivity growth increases once rollout is completed, that impacts diverge after 2033.
36 Martin et al (2012), *Is Telework Effective for Organizations? A Meta-Analysis of Empirical Research on Perceptions of Telework and Organizational Outcomes*. Link
37 The outside in approach would aim to prioritise investment in rural communities at the same time, or in advance of, further deployment in urban areas. This would mean rural areas can benefit from full fibre and close the digital divide.
38 Frontier Economics, for the National Infrastructure Commission. Link.
39 *Superfast Cornwall Interim Report*, Superfast Cornwall / Cornwall Development Company, June 2018
40 SQW, UK Broadband Impact Study (2013). Link.
41 *Adjusted indices of multiple deprivation to enable comparisons within and between constituent countries of the UK including an illustration using mortality rates*, British Medical Journal, Gary A Abel et al. Link.
42 In many occupations – for instance among those employed on a factory or shop floor – working from home is not possible. Although different occupational sectors are not explicitly modelled, calibration therefore ensures that this reality is reflected in the model.
43 In the Census, respondents are only asked to confirm the address of their workplace if they do not tick the 'Mainly work at or from home' box, so Census travel-to-work data does not give any information on these peoples' employment locations. The Cebr model assumes that people who mainly work from home do infrequently commute to a physical place of employment (1 day a week, whereas those mainly commuting to a place of employment do so 4 days a week, working from home 1 day a week), so within the model all workers including those who mainly work from home choose an employment as well as residential location. Therefore, unlike in the Census, being employed in e.g. London and mainly working from home are not mutually exclusive.
44 This means that resident workforce/number employed figures will be very slightly short of the 'true' figures, as there is a small amount of commuting between England/Wales and Scotland/Northern Ireland/other countries – however the effect of this will be very marginal.
45 For London, this includes those who reported that they mainly work at or from home – as they live in London and work from home, by definition they also work in London.
46 Northern Ireland Statistics and Research Agency, Central Survey Unit, Office for National Statistics, Social Survey Division. (2015). *Quarterly Labour Force Survey, January – March, 2011*. [data collection]. 4th Edition. UK Data Service. SN: 6782, http://doi.org/10.5255/UKDA-SN-6782-4
Office for National Statistics, Social Survey Division, Northern Ireland Statistics and Research Agency, Central Survey Unit. (2019). *Quarterly Labour Force Survey, January – March, 2019*. [data collection]. UK Data Service. SN: 8485, http://doi.org/10.5255/UKDA-SN-8485-1
47 Because the question asked in the Quarterly Labour Force Survey is slightly different, the figures it produces are slightly higher – e.g. in 2011 the Census has a figure of 11.4% of workers working from home, compared to the QLFS's 12.7%.
48 Regional results are generated through application of the proportional changes seen in each archetype area to each local authority within those areas, followed by aggregation of these local authorities into the regions.
49 Wales: 3.1m; Northern Ireland: 1.9m.
50 The average commuting trip time in England was 30.5 minutes, according to the Department for Transport's 2016/17 National Travel Survey – values from this survey were used in the specification and calibration of the spatial model.
51 For a 37.5 hour working week.
52 The results produced by the spatial model are implicitly for the 2011 workforce, as they are based on the 2011 Census. Appropriate scaling according to ONS 2016-based population projections ensures that outputs reflect expected workforce growth.
53 Department for Transport, National Travel Survey, Table NTS0412 finds that of commuter trips made in England in 2018, 181 out of 288 journeys (per average for all employed people) were by car.
54 RAC Foundation, *The Car and the Commute: The journey to work in England and Wales*, Table 6, page 11 quotes a DfT figure for the average car commuting distance in England of 9.9 miles or 15.9 kilometres. Link.
55 Department for Transport, Vehicle Licensing Statistics, Table VEH0150 gives 121.3g/km as the average CO2 emissions for newly registered cars in June 2015, the most recent data provided. Average emissions at present will be higher due to the presence of older cars in the stock – the use of a figure for newly-registered cars reflects the likelihood of this falling over time as newer, cleaner cars enter the vehicle fleet.
56 We focus on the potential for employment to increase among women with dependent children, as their employment rate is markedly lower than that for men.
57 *Provision of unpaid care*, Nomis. Link.
58 Government Office for Science, *Future of an Ageing Population*, page 37
59 Also, older workers are dealt with separately in the following section – therefore this avoids any double-counting of older workers with caring responsibilities.
60 Assuming a 45-week working year.
61 Government Office for Science, *Future of an Ageing Population*, page 21
62 *How many UK pensioners are working – and what are they doing?*, BBC News, May 2018. Link.
63 ONS, *Characteristics of Home Workers, 2014*, page 11
64 *Five facts about… older people at work*, ONS, October 2016. Link.
65 ONS 2016-based population projections.
66 Figures from ONS, *Families and the Labour Market*.
67 ONS 2016-based population projections.
68 *Superfast Cornwall Interim Report*, Superfast Cornwall / Cornwall Development Company, June 2018, pages 36-46.
69 Based on inspection of ONS, *House price to residence-based earnings ratio*, March 2019, Table 5c
70 Coastal areas are growing in population already, but with an imbalance towards people who aren't economically active.
71 *Revitalising rural areas through digitisation: The experience of three rural digital hubs*, European Network for Rural Development, September 2017.
72 RSA, *How Everyone Can Learn and Work in the City of the Future*, RSA, Link.
73 TechUK, Digital Plug-in. Link
74 Total Factor Productivity – the combined productivity of capital and labour in the economy.
75 Frankel and Romer (1999) analysed an international cross section and found an increase of 1 percentage point in the ratio of trade to GDP increases the level of GDP by at least 0.5%, and up to 2%. The effect results from both higher investment and higher total factor productivity.


Cadwch mewn gêr isel
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16%
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