Evaluation of the Superfast Broadband Programme

Technical Appendix 1: Reducing the Digital Divide

February 2023

Ipsos

Contents

Glossary....1
Summary....2
1 Introduction....5
1.1 Background....5
1.2 Evaluation questions....5
1.3 State aid evaluation methodology....6
2 Analytical framework....8
2.1 Theoretical framework....8
3 Programme overview....13
3.1 Target area for Phase 3 contracts....13
3.2 Characteristics of postcodes benefitting from the programme....14
3.3 Delivery....16
3.4 Changes in connectivity in the target area....16
3.5 Take-up of subsidised coverage....18
4 Phase 3 connectivity impacts....20
4.1 Data....20
4.2 Evaluation design issues....20
4.3 Simple difference-in-differences....22
4.4 Regression based difference-in-differences....24
4.5 Difference-in-difference with matched samples....28
4.6 Longitudinal panel models....33
4.7 Control group regression to predict counterfactual treatment group coverage....37
4.8 Crowding out....38
4.9 Cost effectiveness....40
4.10 Overview of findings....41

Glossary

Deadweight	Investments funded by the public sector that would have otherwise been brought forward by the private sector (i.e. would have happened anyway)
Exchange Only Lines	Premises connected directly to the telephone exchange, rather than to a cabinet that is connected to the telephone exchange. These premises tend to be either very close to the telephone exchange or at long distances in remote locations.
FTTC	Fibre to the Cabinet – a technology involving the installation of fibre optic lines to connect the cabinet to the service exchange, with premises connected to the cabinet using the copper network.
FTTP	Fibre to the Premises – a technology delivering very fast broadband speeds, using fibre optic connections across the full connection between the premises and the Exchange.
Gigabit capable coverage	Refers to any technology able to provide download speeds of 1Gbit/s or faster.
NGA	Next Generation Access – broadband technologies capable of delivering superfast speeds, including Wireless, Fibre-to-the-Cabinet, Fibre-to-the-Premises, and cable.
OMR	Open Market Review – a process completed by Local Bodies to obtain information on the commercial plans of network providers to invest in superfast broadband infrastructure.
Overbuild	The deployment of a new broadband network that competes with an existing broadband network operated by a different network provider.
SCT	Speed and Coverage Template – a template developed by Local Bodies describing which postcodes or premises are eligible for subsidised coverage. The network provider completes the template as part of the tendering process to define which postcodes or premises they plan to upgrade as part of the proposed network build.
White area	Premises or postcodes identified as unlikely to receive commercial deployments of superfast broadband infrastructure within 3 years, through the Open Market Review and consultation process.

Summary

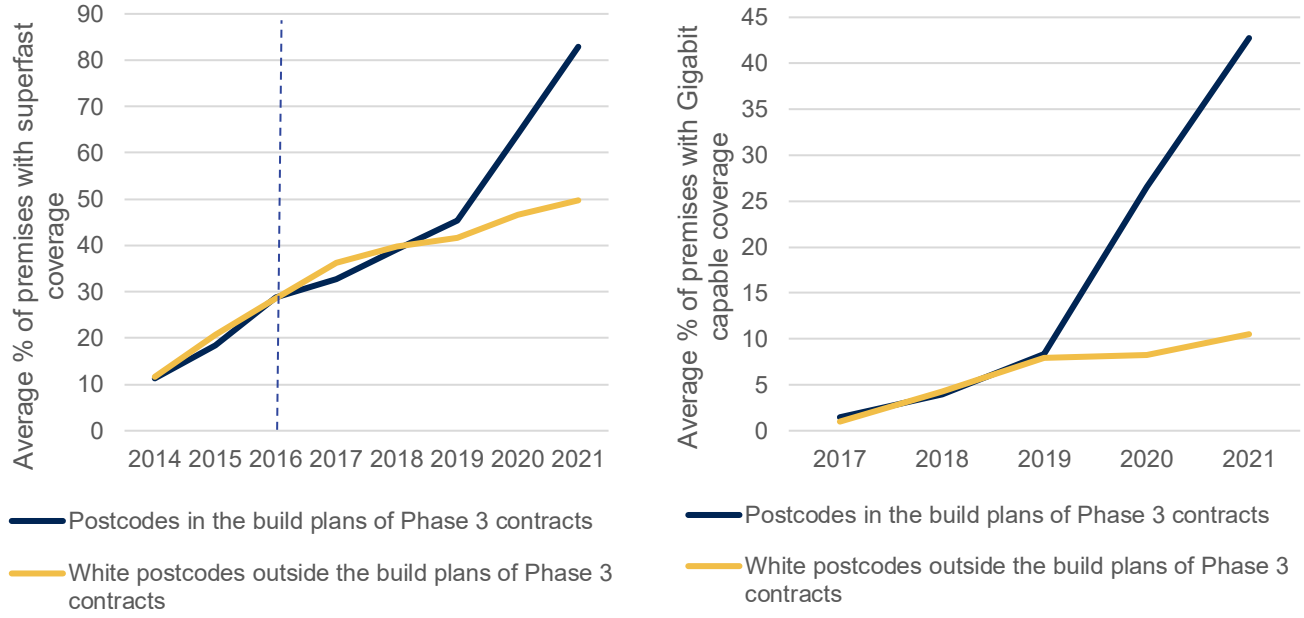
The Superfast Broadband Programme was announced in 2010 in response to concerns that the commercial deployment of superfast broadband infrastructure would fail to reach many parts of the UK. Phase 3 of the Superfast Broadband Programme was funded under a new State aid Decision covering contracts awarded between 2016 and 2020 (State aid SA. 40720 (2016/N)). This paper sets out the results of a series of analyses exploring the impact of the Superfast Broadband Programme on superfast broadband and full fibre/gigabit capable coverage and the take-up of superfast broadband services. The analyses focus on the impacts of Phase 3 of the programme by September 2019.

Overview of results

The findings of the evaluation indicated that Phase 3 of the Superfast Broadband Programme had a significant impact on the availability of superfast and gigabit capable broadband services, particularly as delivery of the programme expanded after 2019.

As illustrated in the following figure, superfast and gigabit capable coverage expanded rapidly in areas benefiting from the programme relative to equivalent postcodes that were not covered by Phase 3 contracts. 80 and 40 percent of premises in the programme area were able to access superfast (at least 30Mbit/s) and gigabit capable services respectively by the end of September 2021.

Figure A: Changes in superfast broadband (at least 30Mbit/s) and Gigabit capable coverage (% of premises), areas in Phase 3 build plans and matched white postcodes[1], 2014 to 2021



Source: C3 reports, Ofcom Connected Nations, Ipsos analysis.

The results of statistical analyses confirmed these results:

- **Impact on broadband coverage:** Subsidised coverage through Phase 3 of the Programme led to significant positive impact on the availability of superfast and gigabit capable broadband services by the end of September 2021. Subsidised coverage increased the share of premises in the programme area able to access superfast speeds by 46 to 47 percentage points, and the share of premises with

[1] Premises or postcodes identified as unlikely to receive commercial deployments of superfast broadband infrastructure within 3 years, through the Open Market Review and consultation process.

gigabit capable coverage by 52 to 56 percentage points above what would have been achieved in the absence of the programme since 2017.

The impact of the programme on NGA availability (i.e. technologies able in principle to deliver superfast, though not necessarily the faster speeds being targeted by Phase 3 contracts) was relatively small, however, indicating that in its absence, most premises would have benefitted from some form of enhanced connectivity (albeit via technologies less able to deliver download speeds of 30Mbit/s or higher).

- **Impact on take-up:** Subsidised coverage led to a significant increase in the maximum download speeds of connections taken by households and/or businesses by September 2021 (34 to 62 Mbit/s). However, the impacts of the programme on average download speeds were relatively small. This indicates that 'early adopters' have taken advantage of the enhanced broadband connectivity enabled by the Programme. However, the Programme had not led to widespread take-up of faster broadband services by September 2021. It should be noted that most subsidised coverage was delivered in 2019 and 2020. As take-up will lag deployment, it is premature to draw any firm conclusions on the impact of the programme on take-up of faster internet services.

Overall, findings on coverage to September 2021 are larger than those evidenced to 2019 and are in line with past research on the Superfast Broadband Programme. The results were also broadly consistent across different methodologies raising confidence in the findings.

Table A: Estimated impact of Phase 3 on areas benefitting from subsidised coverage by September 2021

Outcome	Estimated impact (high to low range)
NGA[2] availability (% of premises)	3.2 to 7.5
Superfast availability (% of premises)	40.9 to 46.6
Gigabit capable availability (% of premises)	43.2 to 56.2
Average download speeds of connections (Mbps)	0 to 0.6
Maximum download speeds of connections (Mbps)	33.7 to 59.2
Average upload speeds of connections (Mbps)	0.9 to 6.3
Number of connections with download speed of 30Mbps+	-1.0 to 3.9

Source: Ipsos analysis. '-' denotes that the result was not statistically significant.

Additionality of subsidised broadband infrastructure

The findings of the evaluation also indicated that few premises would have otherwise received superfast or gigabit capable coverage by the end of 2019, and levels of deadweight were generally limited:

- **Superfast availability:** The Programme is estimated to have increased the number of premises that can access at least superfast broadband services (30Mbit/s or above) by 202,000 to 247,000 by the end of September 2021. The associated rate of additionality ranges from 69 percent to 85 percent. This indicated that while many premises may have received NGA coverage in the absence of the

[2] Refers to technology and NGA does not guarantee Superfast speeds. NGA was selected as the primary outcome measure when the State aid evaluation plan was agreed. However, changes in the availability of local data on connectivity via the Connected Nations report has allowed analysis against a wider set of outcomes.

Programme, these premises would not have been able to access at least superfast speeds (indicating the programme has been highly effective in delivering against its primary objective).

- **FTTP/Gigabit capable coverage:** Subsidised coverage is estimated to have led to 193,000 to 298,000 additional premises with FTTP/Gigabit capable coverage. The rate of additionality ranges from 66 percent to 102 percent (with most estimates in the region of 90 percent). This indicates that the programme has also been highly effective in bringing gigabit capable technologies to rural areas, and these areas were highly unlikely to have benefitted from commercial deployments over the time horizons considered in this evaluation.

- **NGA coverage:** The Programme is also estimated to have led to 17,000 to 40,000 additional premises with NGA coverage. Additionality (i.e. the share of premises benefitting from superfast coverage that would not have in the absence of the programme) is estimated at between 6 and 14 percent, with most estimates towards the lower end of this range. This implies that to a large degree, premises benefitting from the programme would have received some form of NGA coverage in its absence, though any improvements in local connectivity would not have delivered the significant improvements in available speeds achieved through the programme.

Table B: Estimated additionality of NGA, Superfast and Gigabit capable coverage

	Additional premises with enhanced coverage by September 2021	Additionality (share of premises that would not have received enhanced coverage by end of Sep 2021)
NGA availability	17,000 – 40,000	6 – 14%
Superfast availability	202,000 – 247,000	69 – 85%
Gigabit availability	193,000 – 298,000	66 – 102%

Impacts on the programme area

The analyses were also extended to explore the impacts of the Programme on all postcodes included in the build plans of Phase 3 schemes (i.e. including those areas that had not yet benefitted from subsidised coverage) to explore any unintended outcomes of the Programme across the target area as whole.

Previous results of this analysis suggested that the Programme had a negative effect on enhanced broadband availability across the overall Programme area (suggesting it had delayed coverage in some area). Such effects are no longer visible now the analysis has been extended to 2021, indicating that any negative effects via the delay of deployment were only temporary.

1 Introduction

This paper sets out the results of a series of analyses exploring the impact of the Superfast Broadband Programme on superfast broadband and full fibre/gigabit capable coverage and take-up of superfast broadband services, focusing on the impacts of Phase 3 of the Programme.

1.1 Background

The Superfast Broadband Programme was announced in 2010 to respond to concerns that the commercial deployment of superfast broadband would fail to reach many parts of the UK due to the cost of installing the technology relative to expected revenues.[3] On the expectation that extending superfast broadband coverage to these areas would produce economic, social and environmental benefits that would not be captured by suppliers, the Government established the programme to provide £530m of public resources to fund further deployment with the aim of enabling 90 percent of UK premises to access superfast broadband speeds by early 2016. The Programme was extended in 2015, with a further £250m made available to extend coverage to 95 percent by the end of 2017.

The Superfast Broadband Programme was extended a second time under a new State aid approval[4] covering the 2016 to 2020 period. Contracts awarded under this State aid scheme (sometimes known as Phase 3) are the focus of this analysis. These projects had a greater focus on full fibre connectivity than those funded in prior phases, aligning with broader Government objectives to increase Fibre to the Premises (FTTP) coverage in the UK. This third phase evolved from a series of pilots that sought to explore how coverage could be extended past 95 percent of UK premises. There were 67 Phase 3 contracts underway at the time of writing.

1.2 Evaluation questions

This analysis tackles three key evaluation questions defined in the State aid evaluation plan[5] agreed between BDUK and the European Commission. These are:

- **Question 1:** To what extent has the aid resulted in increased access to a Next Generation Access[6] (NGA) network in white[7] NGA areas?
- **Question 2:** To what extent has the target of the intervention been used and what speeds are available?

[3] DCMS and Rt Hon Jeremy Hunt MP (2010) Media Keynote Speech, the Hospital Club. Available at: https://www.gov.uk/government/speeches/media-keynote-speech (accessed March 2022).

[4] European Commission (2016) SA. 40720 (2016/N) – National Broadband Scheme for the UK for 2016-2020. Available at: https://ec.europa.eu/competition/state_aid/cases/263954/263954_1760328_135_4.pdf (accessed March 2022).

[5] DCMS (2017) National Broadband Scheme Evaluation Plan. Available at: https://www.gov.uk/government/publications/national-broadband-scheme-evaluation-plan

[6] Next Generation Access networks are defined in the 2013 Broadband Guidelines as having the following characteristics: (i) deliver services reliably at a very high speed per subscriber through optical (or equivalent technology) backhaul sufficiently close to user premises to guarantee the actual delivery of the very high speed; (ii) support a variety of advanced digital services including converged all-IP services and (iii) have substantially higher upload speeds (compared to basic broadband networks). NGA networks were considered at the time to include (i) fibre-based access networks (Fibre to the Cabinet and Fibre to the Premises), (ii) advanced upgraded cable networks, and (iii) certain advanced wireless access networks capable of delivering reliable high speeds to the subscriber. See European Commission (2013) EU Guidelines for the application of State aid rules in relation to the rapid deployment of broadband networks. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013XC0126(01)&from=GA (accessed March 2022).

[7] White areas are defined in the 2013 Broadband Guidelines as those in which there is no broadband infrastructure, and it is unlikely to be developed in the near future. Ibid.

- **Question 6:** Is the gap funding model efficient compared to alternative schemes?

1.3 State aid evaluation methodology[8]

The methodology used for the analysis builds on the approach set out in the State aid evaluation plan (and is consistent with prior analyses). This involved two main approaches:

- **Difference-in-differences:** This approach compares changes in NGA coverage and take-up between June 2016 and September 2021 on postcodes benefitting from Phase 3 contracts and a comparison group of postcodes that were identified as white in the Open Market Review process but were not included in the build plans of Phase 3 contracts. The evaluation plan defined postcodes benefitting from the Programme as those that received subsidised coverage by September 2021 (i.e. areas in the build plans of these schemes, but had not yet benefitted from the Programme, were not considered part of the treatment group).

- **Modelling of coverage in white postcodes (control group regression approach):** This involved the development of a statistical model to explain the evolution of coverage and take-up on white postcodes that were not included in the build plans of Phase 3 contracts between 2016 and 2021. This model was used to predict NGA coverage on postcodes benefitting from Phase 3 contracts in the counterfactual scenario in which the Programme had not been funded. Predicted NGA coverage was subtracted from observed coverage to estimate the impact of the programme.

Several extensions were made to the above methodology that was defined in the State aid evaluation plan to extend the scope of the analyses and probe robustness:

- **Range of outcomes:** The focus of the methodology defined in the State aid evaluation plan was on NGA coverage and take-up. This choice was based on the data available at the time. However, the availability of NGA services is only an approximation of the goal targeted by the Programme, which is to bring forward superfast (30Mbit/s) coverage in areas that would not otherwise benefit from commercial deployments. NGA technologies may not always deliver superfast speeds (for example, if premises are too distant from a serving cabinet upgraded to FTTC). Improvements in data availability has enabled a broader range of outcomes to be explored – including superfast coverage and take-up, and the availability of technologies capable of delivering gigabit speeds (1,000Mbit/s).

- **Selection on observables:** The difference-in-differences approach set out in the State aid evaluation plan did not account for systematic but observable differences between the proposed treatment and comparison groups that could bias results. Several additional steps were taken to control for observable differences between the two groups. This included adding control variables to regression-based difference-in-difference models and using statistical matching methods to ensure that postcodes benefitting from the programme were only compared to postcodes outside of Phase 3 build plans where they shared similar characteristics.

- **Intention-to-treat estimates:** The State aid evaluation methodology focused on the impact of the Programme on those postcodes that had received subsidised coverage by the time of the analysis. This could potentially lead to biased estimates of the impact of the programme if there are systematic but unobserved differences between those postcodes that received subsidised coverage early in the build programme and those expected to benefit in the future. Supplementary analyses were also

[8] All analyses were implemented with STATA software package.

carried out using all postcodes in the build plans of Phase 3 contracts as the treatment group for the analysis that are more robust to this potential issue.

2 Analytical framework

This section sets out an overall framework for the analysis. This defines the key hypotheses the evaluation is aiming to test and provides an overarching theoretical framework for the analysis (i.e. a theory of change). The framework was initially developed through a combination of consultations with BDUK officials and the application of economic theory to the delivery model adopted to implement the programme.

2.1 Theoretical framework

The Superfast Broadband Programme aims to increase the number of premises covered by superfast broadband infrastructure. This objective is achieved by subsidising network providers to extend their networks to areas that would not be commercially viable otherwise.

2.1.1 Programme delivery model

Making subsidies available for infrastructure delivery involves a risk that private providers have an incentive to seek public funds for (deadweight) investments that they would have made anyway, enabling them to earn a higher rate of return. The impact of the Programme on the number of premises covered by superfast broadband services will be limited where public resources are allocated to schemes that would have been considered commercially viable otherwise. A range of mechanisms were introduced to mitigate against these risks:

- **Allocation of subsidies:** Subsidies were allocated to Local Bodies (responsible for tendering and awarding contracts to deliver infrastructure upgrades) based on BDUK's assessment of the gap funding[9] needed to upgrade each cabinet in the UK. In Phase 1, BDUK funding was allocated based on local shares of the gap funding requirement to reach the initial target of 90 percent superfast coverage in each area. In Phase 2, resources were allocated based on the gap funding needed to reach 95 percent coverage at the national level at the lowest cost[10]. For Phase 3, resources were allocated to achieve the greatest increase in coverage for the available funding (which included resources brought by the Local Body). Several local authorities were deemed ineligible for BDUK support because existing commercial plans were already extensive.

- **Open Market Review (OMR) and public consultation:** Local Bodies were required to manage an OMR and public consultation process before they issued tenders. The first stage of this process involved requesting suppliers to describe their commercial plans to roll-out basic and superfast broadband coverage over the next three years. This process classified premises (postcodes in Phase 1 and 2) into three groups:

  - **White areas** where there were no credible commercial plans to roll-out superfast broadband within three years.
  - **Grey areas** where one provider was offering or expected to offer superfast broadband services within three years, and,
  - **Black areas** where multiple providers were offering or expected to offer superfast broadband.

  This view on future superfast broadband availability was then subject to public consultation.

[9] The level of subsidy required to make the investment sufficiently profitable for the supplier.

[10] However, under initial calculations, this would have resulted in Wales, Scotland and Northern Ireland receiving a smaller share than would be implied by their population shares. A share of funds available equivalent to population share was allocated to the two DAs, while resources were distributed across England in the manner suggested.

- **Tendering:** This view on the near term roll out of broadband at the local level was expressed in a Speed and Coverage Template (SCT) used in local tendering exercises. Only 'white' premises were eligible for subsidised infrastructure, with competing providers outlining which premises they proposed to cover for the available funding. Network providers were required to provide a Project Financial Model (PFM), which included estimates of the overall costs associated with delivering the project, take-up assumptions and expectations of future revenues and on-going operational costs. This model provided an estimate of the internal rate of return (IRR) associated with the project without subsidy. The subsidy offered aimed to equalise the IRR over a seven-year period with the suppliers Weighted Average Cost of Capital (WACC)[11].

- **Underspend:** Protections for the public sector against the risk that suppliers overestimated their delivery costs were put in place by introducing a mechanism to recover underspend. The underlying principle was that the supplier would fully invest its contracted funding. In the event of any underspend, the supplier was required to place unused funds in an Investment Fund to help resource further schemes or extend the coverage to a greater number of premises than originally offered.

- **Take-up clawback:** Further protections for the public sector were introduced through 'take-up clawback' clauses in contracts. If take-up proved to be higher than anticipated at the tendering stage then suppliers were required to return a share of the excess revenues to the Investment Fund based on the investment ratio (and again, these funds could be recycled to support further coverage). Take-up clawback was capped such that the amount returned to the public sector could not exceed the value of the subsidy awarded.

2.1.2 Factors influencing additionality

While the programme involved mitigating actions to minimise the risk of deadweight, several factors could influence the size of the impacts of the programme:

- **Accuracy of information gathered through the OMR:** The level of additionality associated with the programme will be dependent on how far the OMR process was effective in accurately identifying 'white' postcodes where no commercial deployment of NGA networks was planned. If the OMR incorrectly identified 'black' or 'grey' areas as 'white' and eligible for subsidies, there is a danger that public funding could fund superfast infrastructure in areas that would otherwise have benefitted from commercial deployments. Threats to the accuracy of the information gathered through the OMR include:

  - **Comprehensiveness:** The OMR process aimed to reveal the commercial plans of all network providers that could credibly deploy superfast networks over the timescales of interest. This required Local Bodies to engage effectively with local network providers. If some potential providers did not provide their commercial plans, there is a risk that some premises are mistakenly identified as 'white' and eligible for subsidies. The comprehensiveness of the data gathered is also linked to the standards of evidence applied by Local Bodies when reviewing the credibility of the commercial plans provided by network providers. Evidence from the broader evaluation of the Programme indicated that in some cases, network providers were unable to provide plans with a minimum level of granularity, detail or certainty and their submissions were dismissed. If these plans were (or would have been) taken forward, this would have resulted in some postcodes or premises mistakenly marked as eligible for subsidies. Qualitative research with Local Bodies also

[11] This assumes that the minimum IRR on the project should equal the supplier's cost of capital for the project to be viable.

provided evidence that some network providers were reluctant to provide their commercial deployment plans as this could influence the investment decisions of their competitors.

- **Strategic behaviour during the OMR process:** It could be anticipated that some network providers would see an incentive to understate their commercial plans during the Open Market Review process if it increased the likelihood they could obtain subsidies for investments they would have made anyway. However, suppliers that did not intend to seek subsidies (for example, if they were discouraged by open wholesale access requirements) may have experienced incentives to overstate their commercial plans to preserve local market dominance or prevent the emergence of subsidised competitors. This latter issue may not affect additionality as it would imply some postcodes were mistakenly marked as ineligible for subsidies but could have economic or social costs (e.g. if the publication of the resultant coverage maps promoted business investments in areas where superfast coverage did not ultimately come forward).

- **Dynamic nature of commercial deployments:** The OMR provided a static view of future commercial deployment plans. However, network providers operate in a dynamic environment in which deployment plans evolve in response to new information. On-going increases in demand for superfast services observed since the programme was launched will increase the potential revenues that can be earned, making some investments profitable that previously were not. Regulatory innovation[12] has reportedly allowed competing network providers to access Openreach's Physical Infrastructure Access (PIA) product more efficiently, reducing the cost of network deployment via access to the dominant provider's ducts and poles. The length of investment planning cycles (reportedly 12 to 24 months) will also inhibit the ability of network providers to supply concrete deployment plans for extensive periods in the future. As such, some 'white' postcodes may become 'black' over time, potentially resulting in some premises receiving superfast coverage earlier than they otherwise would have.

- **Network provider behaviour during the tendering process:** Given that it is not possible to perfectly observe the future commercial plans of network providers, contractual mechanisms provided further protection against the risk that public sector resources were deployed to take forward schemes that were commercially viable. The underspend and take-up clawback mechanisms aimed to reduce the ability of network providers to exploit their superior information to overstate the gap funding requirement. Overstatement of costs at the tendering stage would be recovered via the underspend clawback mechanism[13]. A share of any understatement of future revenues would also be recovered via the take up clawback mechanism. Understating expected costs or overstating take-up expectations (e.g. to improve the competitiveness of tenders submitted) could result in the supplier ultimately taking a loss. These protections are internal to the relevant infrastructure provider and would not limit subsidies being allocated to schemes that overbuild or discourage planned deployments by competing suppliers.

  The effectiveness of these mechanisms will be linked to the level of competition for the subsidies awarded. In the absence of competition, the network provider can potentially transfer the risk of making unprofitable investments to the public sector by assuming low levels of take-up. This strategy would increase the level of gap funding required to make the project viable, which would be returned to the public sector only if the project was a commercial success. This approach would be less viable

[12] Such as Ofcom's remedies for Openreach's Physical Infrastructure Access product announced in the 2018 Wholesale Local Access Review See Ofcom (2018) Wholesale Market Review: Statement – Volume 3 (physical infrastructure access remedy). Available at https://www.ofcom.org.uk/__data/assets/pdf_file/0023/112469/wla-statement-vol-3.pdf (accessed August 2018).

[13] Unless subsidies encourage less efficient delivery.

in the presence of competition, as it would reduce the value for money associated with the tender and increase the likelihood the procurement was lost to a competitor. Phase 3 contracts were all awarded through an open OJEU process and many tenders attracted multiple bids.

- **Delivery of parallel programmes:** BDUK is delivering several parallel programmes aiming to stimulate deployment of FTTP (demand led interventions). These include the Gigabit Connection Voucher Scheme (GBVS) and the Local Full Fibre Network (LFFN) programme.

2.1.3 Indirect impacts

The above processes may also be expected to have the following indirect impacts on local connectivity:

- **Crowding out:** The provision of subsidies for Superfast Broadband Programme investment has the potential for two forms of 'crowding out':
  - **Discouragement effects:** The build plans of Phase 3 schemes were published and revealed those 'white' postcodes that would benefit from subsidised coverage. In cases where other suppliers had plans to extend their networks to these areas that were not identified by the OMR process, the presence of subsidised competitors may have reduced the profitability of those investments and in some cases, led to their abandonment.
  - **Price effects:** There may also have been negative impacts on 'grey' and 'black' areas if suppliers faced capacity constraints – either in the labour market or in credit markets (for smaller suppliers). If firms are not able to expand their overall capacity to deliver the programme of subsidised infrastructure improvements, then this may result in delays or abandonment of schemes planned without subsidy, offsetting the effects of the programme in 'white' areas. Consultations with BDUK suggested that this risk was acknowledged and mitigated by the timing of the first two phases programme, which began as the main suppliers were completing the bulk of their commercial roll-out. The risk is potentially greater for Phase 3 with these contracts entering delivery at a time when suppliers are beginning their commercial rollout of FTTP.
- **Crowding-in:** Take-up of subsidised superfast broadband availability was higher than expected (at least during Phase 1 of the Programme). It is possible that the Programme helped demonstrate the commercial viability of infrastructure investment in the areas targeted, encourage investments in other areas to maximise their returns. This would be visible in the form of accelerated broadband coverage in 'white' areas that were not targeted by suppliers. However, successive announcements that the Government was providing further public subsidy could also have influenced supplier expectations, causing them to hold back investment expecting further funding to become available. Experiences with commercial deployments may also have demonstrated commercial viability. In this case, crowding-in effects could not be wholly attributed to the programme.
- **Competition:** Finally, the Programme may have led to changes in the parameters of competition and the market shares of network providers:
  - **Wholesale access requirements:** In principle, the Programme was targeted at 'white' postcodes that could not sustain a single provider of superfast infrastructure without subsidy. As such, the programme can be expected to create local monopolies. However, the Programme required subsidised network providers to provide open and non-discriminatory wholesale access to physical infrastructure (ducts, poles, cabinets, masts), dark fibre, copper loop unbundling, and antenna on the subsidised portion of the network (with charges set with reference to benchmark

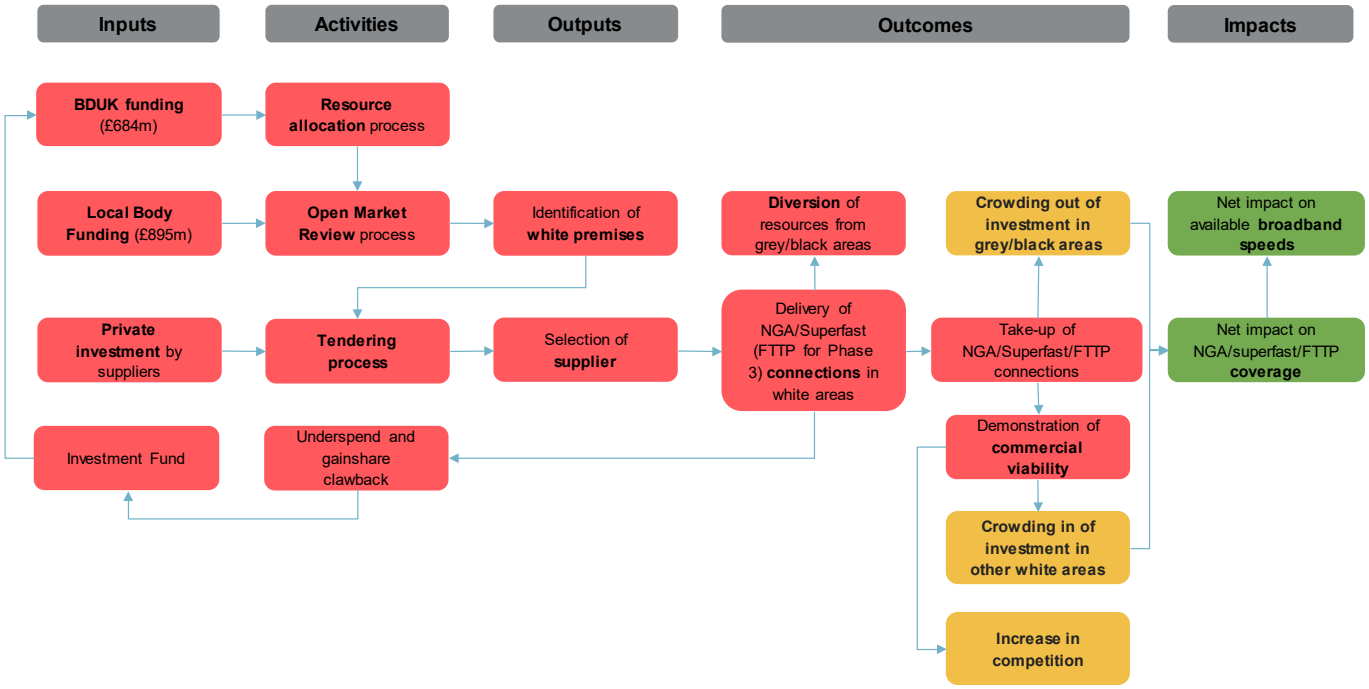
wholesale market prices). These requirements could potentially stimulate additional competition in wholesale or retail markets.

- **Overbuild:** Less directly, the nature of broadband technologies may have led to competitive distortions by increasing competition on 'grey' or 'black' postcodes. The cabinets upgraded to FTTC technologies will serve multiple premises. Some of these premises will have benefited from superfast coverage provided by competing network providers. While BDUK will not have funded the upgrade of these premises, the cabinet itself may not have been upgraded in the absence of the programme. In these cases, the entry of a subsidised competitor may have eroded the market shares and/or the profitability of incumbent providers.

2.1.4 Logic model

The logic model below summarises the processes described above and some of the expected impacts of the Programme. This focus of this report is on the net impact of the Programme on superfast coverage and available broadband speeds.

Figure 2.1: Logic model – connectivity impacts of the Superfast Broadband Programme



Source: Ipsos analysis

3 Programme overview

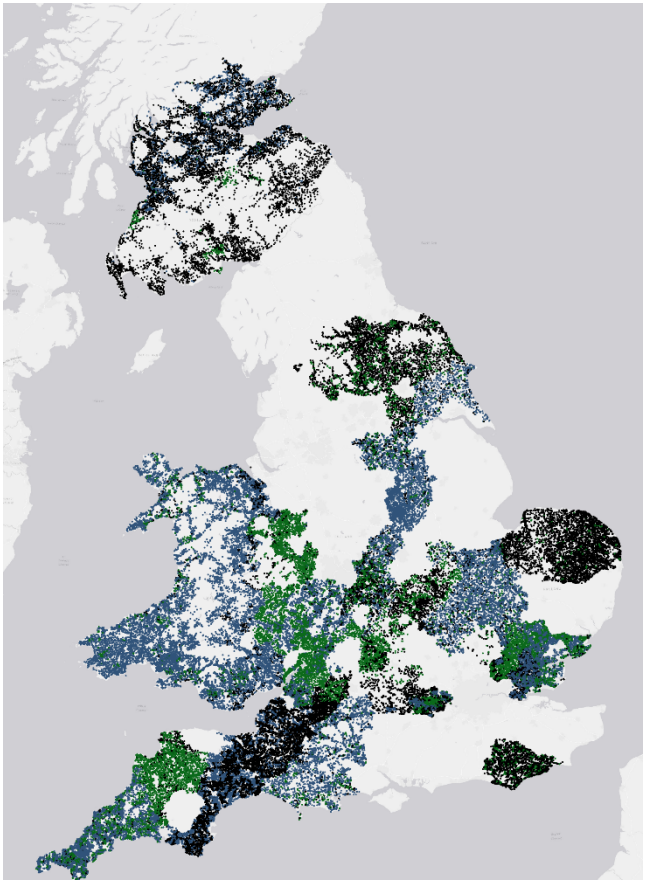
This section provides an overview of the delivery of the Superfast Broadband Programme between 2012 and 2021 with an emphasis on the delivery of Phase 3 contracts. This section draws on an analysis of management data describing the target areas of contracts awarded under the programme and delivery of the programme to September 2021.

3.1 Target area for Phase 3 contracts

The target areas for the Programme were defined in Speed and Coverage Templates (SCTs) developed by Local Bodies based on the Open Market Review. The template identifies those premises that are not expected to receive superfast coverage under the commercial plans of network providers (white postcodes) and are therefore eligible for subsidised coverage.

These templates are completed by network providers as part of the tendering process, where they set out which premises will be upgraded as part of the proposed network build (the build plan). Premises on 64,000 postcodes were included in the build plans of Phase 3 contracts (four percent of the postcodes in the UK). Premises on 54,000 postcodes were identified as eligible for the programme but were not included in the build plans of Phase 3 contracts.

Figure 3.1: Eligible postcodes inside and outside of the build plans of Phase 3



Source: SCT templates, C3 Reports, Ipsos analysis; green denotes built to as of September 2022, black are in build plans to be delivered to and blue are other white postcodes

It should be noted that the SCTs do not provide a complete record of white, grey, and black premises across the UK. SCTs were only available for those areas for which contracts were awarded. Additionally,

the premises listed in Phase 3 SCTs only provided partial coverage of the territory covered by the relevant Local Body.

Table 3.1: Overview of Speed and Coverage Templates, Phase 3 contracts

Status	Phase 3	
	Number of postcodes	% of postcodes in UK
White postcode within build plan defined in SCT	64,473	4.3
White postcode out of build plan defined in SCT	53,729	3.5
Grey or black postcode in SCT	43,602	2.6
Total	**161,804**	**10.7**
Number of SCTs	65[14]	

Source: SCT templates, Ipsos analysis

3.2 Characteristics of postcodes benefitting from the programme

The postcodes included in the build plans of Phase 3 contracts were linked to other datasets to obtain information on their characteristics before the Programme began. An overview of their key features in relation to other white postcodes that did not benefit from the Programme is provided in the Table 3.2. The table highlights that those postcodes included in the build plans of local schemes differed in several ways from other postcodes eligible for investment through the programme:

- **Availability & coverage:** Superfast broadband penetration was lower in postcodes included Phase 3 build plans than in other white postcodes that were eligible for investment (in both 2012 and 2016). This is also reflected in measures of take up, including the average and maximum speeds of connections and the number of superfast connections taken by consumers located on the postcode.

- **Network characteristics:** Areas in the build plans covered by Phase 3 contracts were also more likely to exhibit characteristics that would increase the costs of deployment or reduce commercial viability. Premises included in the build plans of Phase 3 contracts were characterised by longer line lengths to the serving cabinet - which are more expensive to upgrade as copper lines from the serving cabinet are less able to deliver at least superfast speeds, requiring additional investment in fibre. Demand density was also lower – with lower numbers of delivery points per exchange/cabinet and lower population and premises density. This reduces the number of customers that can potentially be served and the potential revenues that can be earned. BDUK modelling completed in 2014 also suggested that the estimated cost of upgrading the serving cabinet would be higher.

- **Area characteristics:** Postcodes included in the build plans of Phase 3 contracts were more likely to be rural in nature (74 percent of postcodes compared to 64 percent of postcodes eligible but not included in build plans). Employment and unemployment rates in the local authorities were similar across groups, though average wages were lower in those areas included in Phase 3 build plans than in areas not included in build plans.

This indicates network providers selected premises that were costlier to upgrade and were characterised by weaker demand side characteristics. This is the reverse of the patterns observed for Phase 1 and

[14] A total of two SCTS were excluded as they did not provide the required detail and no alternatives were available.

Phase 2[15] of the Programme. This may be related to the comparatively high levels of penetration in white postcodes that were not included in the build plans of Phase 3 contracts. Where existing levels of penetration is high, the remaining unserved premises may be concentrated in relatively small pockets. It may not be cost effective to build out networks to fill these gaps in provision. Network providers may have targeted communities with low levels of existing penetration to maximise the size of the local markets that could be addressed.

Table 3.2: Characteristics of postcodes included in Phase 3 build plans

Characteristics	Postcodes in Phase 3 build plans	Postcodes receiving subsidised coverage by Sep. 2021	White postcodes not included in Phase 3 build plans
Broadband availability and take-up in 2012			
% of postcodes with Next Generation Access	14.9	14.3	39.6
Average maximum download speed (Mbit/s) of connections[16]	9.3	10.0	13.4
Average download speeds (Mbit/s) of connections	6.2	9.7	13.9
Broadband availability and take-up in 2016			
% of postcodes with Next Generation Access	70.4	72.4	79.8
% of postcodes with superfast (30Mbit/s) access	25.2	25.2	55.6
Average number of premises on postcode with superfast connections[17]	1.7	5.1	8.1
Network characteristics in 2013			
Length of line from exchange to premises (m)	3,588	3,050	2,165
Share of premises with exchange only lines (%)	22.3	13.0	4.5
Delivery points at serving exchange	6,231	10,765	17,601
Delivery points at serving cabinet	242.7	300.5	381.0
% of postcodes in Virgin Media footprint	0.7	14.7	48.4
Number of residential delivery points	11.1	14.9	19.6
Number of non-residential delivery points	1.0	1.1	0.7
Estimated cost to upgrade serving cabinet (£)	65,549	63,939	61,834
Estimate upgrade cost per premises upgraded (£)	325.5	307.9	179.3
Area characteristics in 2013			
% of postcodes in rural areas	74	54	64
Working age population (in Output Area)	170	195	200
Population aged 65+ (in Output Area)	62	55	50
Population density in OA (population per square km)	634	1,659	4,412
Premises density in OA (premises per square km)	402	988	2569
Gross weekly earnings in LA (£)	465	537	519
Employment rate in LA (%)	71.8	74.4	71.1
Unemployment rate in LA (%)	6.1	7.1	8.2

Source: Ipsos Analysis

[15] BDUK (2018) Superfast Broadband Programme Evaluation: Annex A – Reducing the Digital Divide.

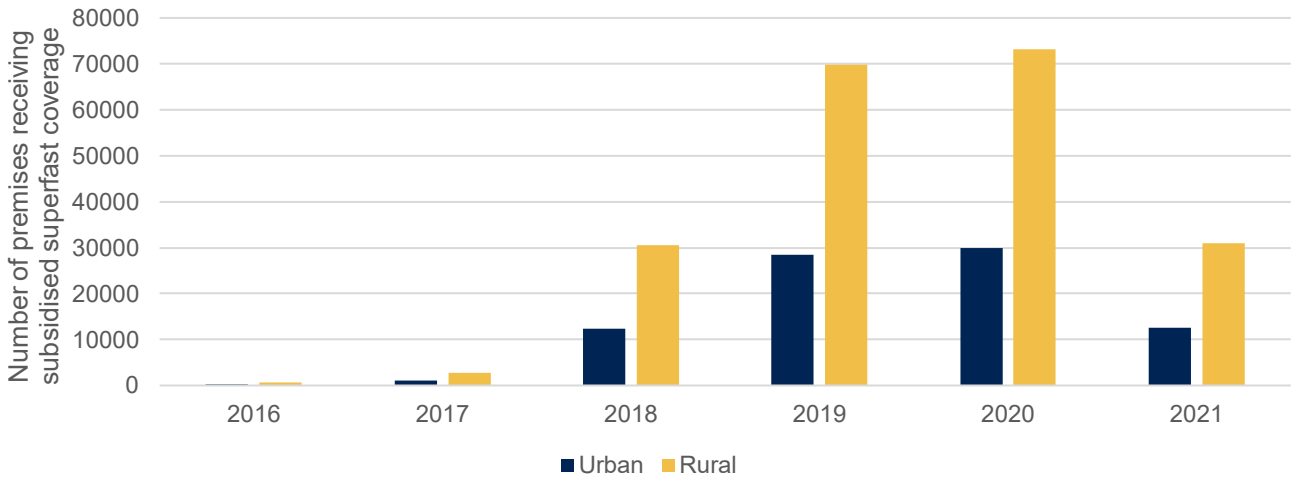
[16] Note that this does not factor in the number of premises on a postcode able to reach a certain maximum download speed

[17] There were around 11.3 premises per postcode on postcodes in the build plans of Phase 3 schemes.

3.3 Delivery

Delivery of the Programme began in 2016 and analysis of C3 reports provided by BDUK indicated that around 292,618 premises received subsidised coverage by September 2021 (over 37,000 postcodes). It should be noted that most coverage was towards the latter stages of the time horizon for this evaluation. As take-up of superfast broadband services will follow deployment, it should be noted that the estimates of the impact of the programme presented in this paper are likely to understate the eventual impact of the programme on take-up.

Figure 3.2: Number of premises receiving superfast (30Mbit/s[18]) coverage subsidised by BDUK, areas for which Phase 3 SCTs are available, 2016 to 2021



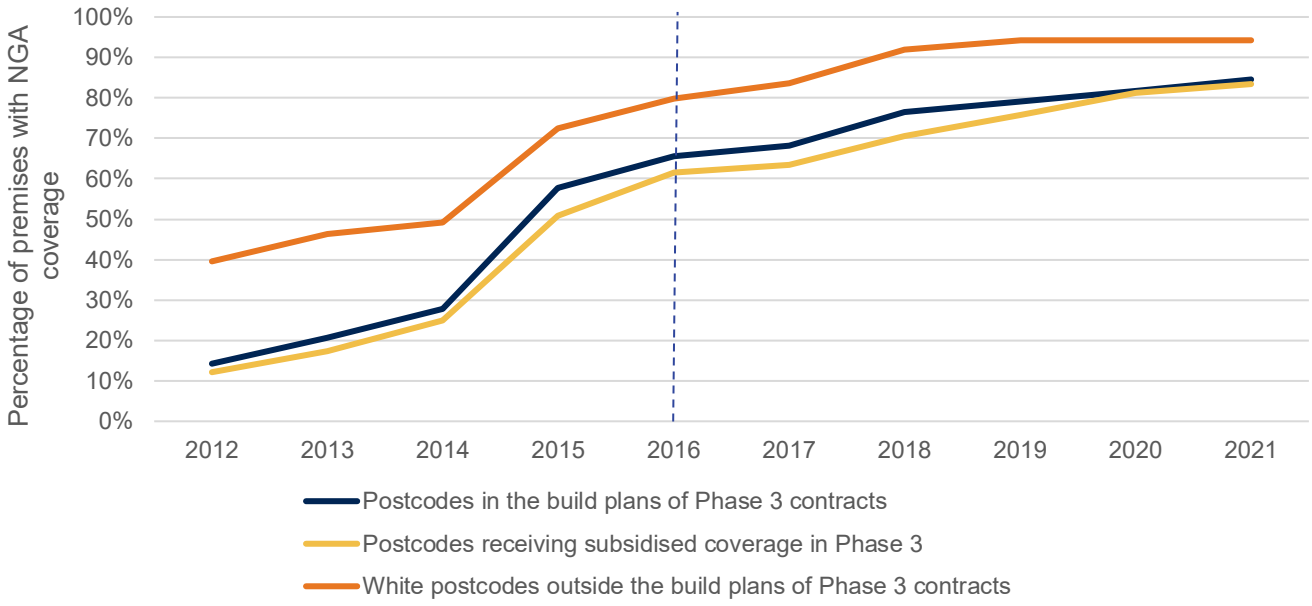
Source: C3 reports, Ipsos analysis.

3.4 Changes in connectivity in the target area

The following figure shows changes in availability of Next Generation Access (NGA) broadband (FTTC, FTTP/Gigabit capable, Wireless or Cable) between 2012 and 2021 on white postcodes included and excluded from the build plans of Phase 3 contracts. The percentage of postcodes included in the build plans of Phase 3 contracts with NGA coverage rose from 66 percent to 85 percent between June 2016 and September 2021. NGA coverage was persistently higher on white postcodes outside of Phase 3 build plans (rising from 80 percent to 94 percent over the same period).

[18] 24MBits for Phase 1 and Phase 2

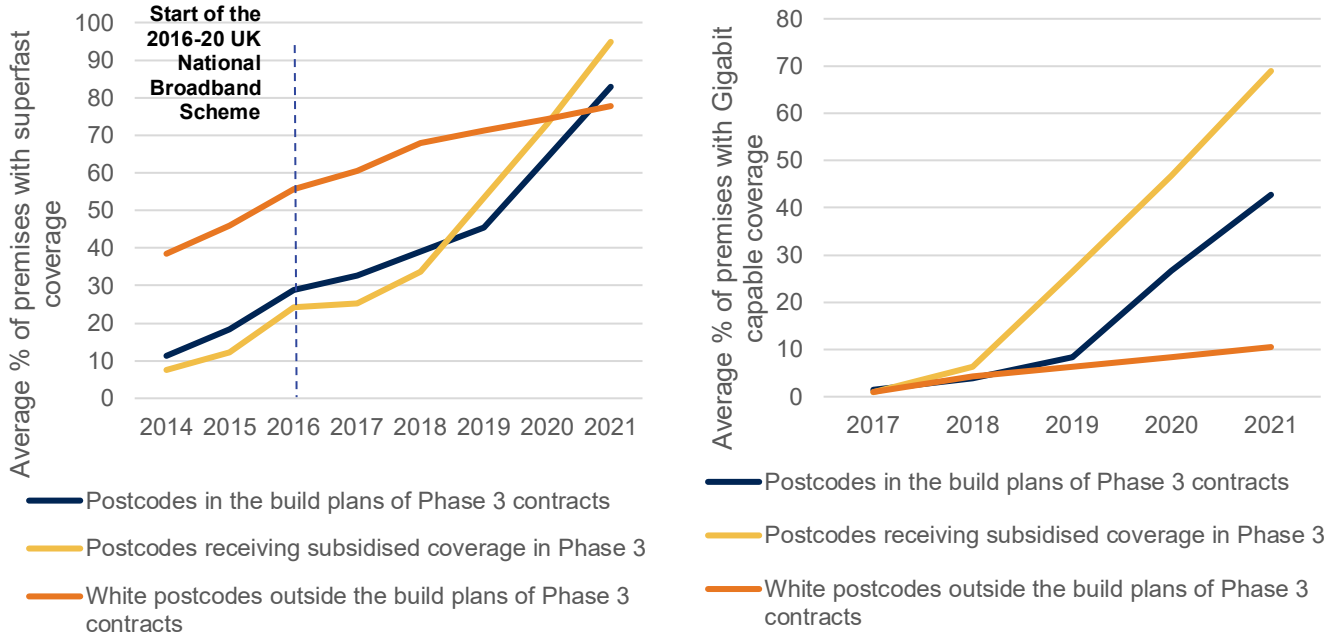
Figure 3.3: Changes in Next Generation Access (NGA) coverage – areas in Phase 3 build plans and other white postcodes, 2012 to 2021



Source: C3 reports, Ofcom Connected Nations, Ipsos analysis.

Superfast broadband coverage rose at similar rates in areas covered by Phase 3 build plans and other white postcodes between 2016 and September 2019 (from 29 to 45 percent and from 55 to 71 percent respectively). However, in line with the delivery profile, areas within Phase 3 build plans saw coverage expand much more rapidly between 2019 and 2021, rising from 45 percent to over 80 percent of premises over the period. FTTP/Gigabit capable coverage also rose more rapidly in the programme area than on other white postcodes.

Figure 3.4: Changes in superfast broadband (at least 30Mbit/s) and Gigabit capable coverage (% of premises), areas in Phase 3 build plans and other white postcodes, 2014 to 2021



Source: C3 reports, Ofcom Connected Nations, Ipsos analysis. Note data on FTTP coverage is only available from 2017 onwards.

3.5 Take-up of subsidised coverage

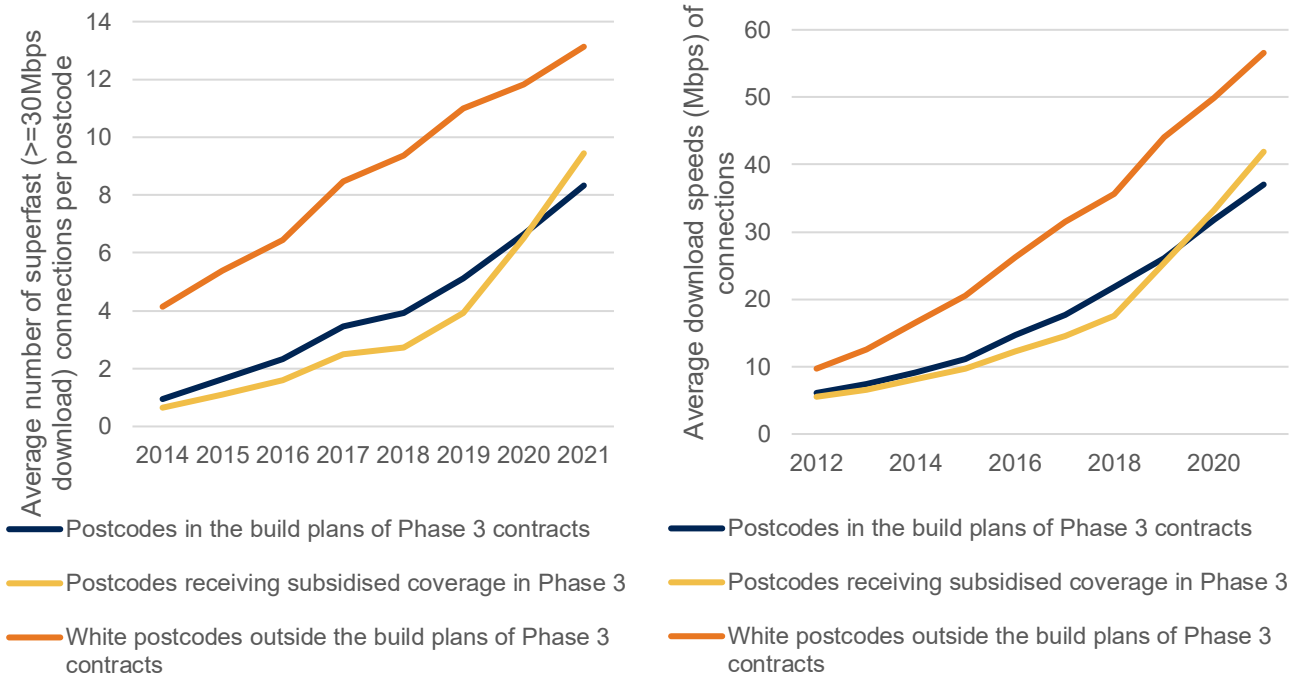
Take-up of superfast broadband coverage also rose rapidly in the programme area relative to other white postcodes by September 2021:

- **Number of superfast (30Mbit/s) connections:** The average number of superfast connections on postcodes in the build plans of Phase 3 schemes grew from 2.3 in 2016 to 8.3 in 2021. Connections on postcodes receiving subsidised coverage rose even more rapidly, from 1.6 in 2016 to 9.4 in 2021. The number of superfast connections rose at lower rate on other white postcodes not included in the build plans of Phase 3 schemes.

- **Average download speeds:** The average download speeds of connections on postcodes included in the build plans of Phase 3 contracts rose from 15 Mbit/s to 37 Mbit/s between 2016 and 2021 (152 percent). Growth in average download speeds was even more rapid on postcodes receiving subsidised coverage by September 2021 (rising to 42 Mbit/s). However, average download speeds remained lower than across other white postcodes that were not covered by the programme over the period.

As in 2020, there were more marked differences in the maximum download speeds of connections (shown in Figure 3.6). Maximum downloads speeds on the postcodes included in the build plans of Phase 3 schemes rose at a faster rate to those on other white postcodes. Maximum download speeds again rose most rapidly in those areas that had received subsidised coverage. Areas receiving coverage by September 2021 saw average maximum download speeds reach 124Mbit/s. This is indicative of users taking advantage of the faster speeds made available through FTTP (the availability of which was more widespread in these areas in 2021).

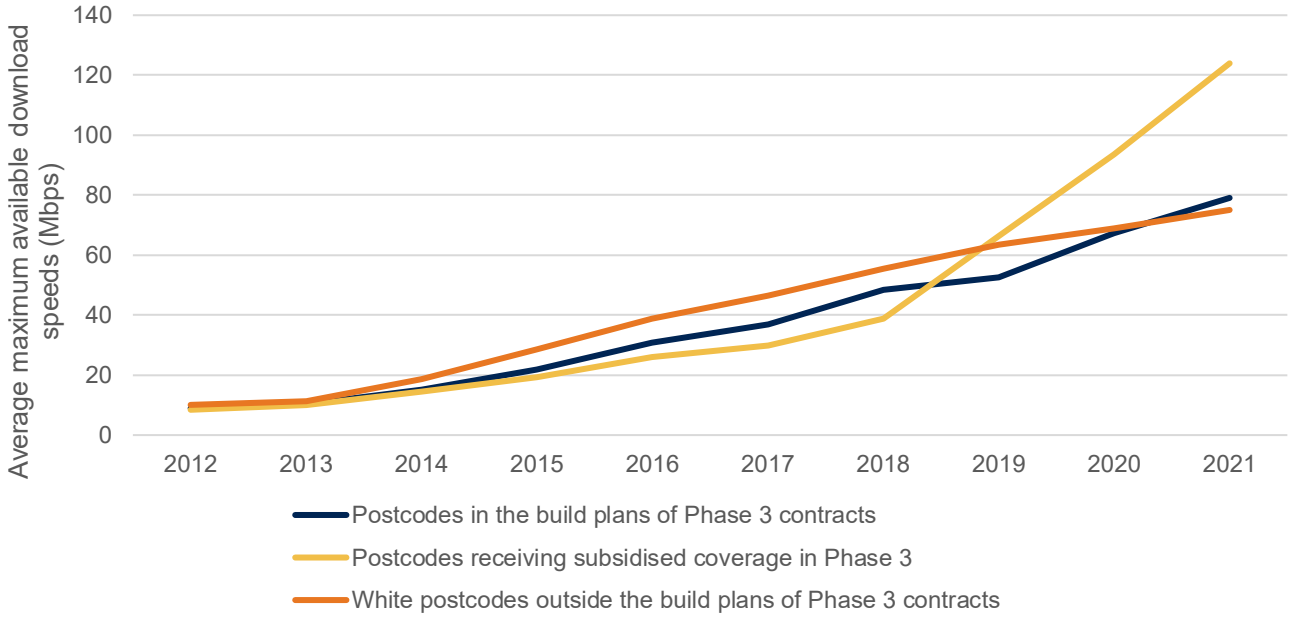
Figure 3.5: Number of superfast (30Mbit/s) connections and average download speeds of connections – areas in Phase 3 build plans and other white postcodes, 2014 & 2012 to 2021



Source: C3 reports, Ofcom Connected Nations, Ipsos analysis[19].

[19] Data on superfast connections only available from 2014 onwards in Ofcom Connected Nations data

Figure 3.6: Maximum download speeds of connections, areas in Phase 3 build plans and other white postcodes, 2016 to 2021



Source: C3 reports, Ofcom Connected Nations, Ipsos analysis.

4 Phase 3 connectivity impacts

This section provides an assessment of the impact of Phase 3 contracts on the connectivity outcomes by September 2021. The methodology for this analysis builds on the approaches defined in the State aid evaluation plan for the programme.

4.1 Data

The data utilised in the analysis set out in this paper was derived from a variety of sources. The table below provides an overview of the datasets used.

Table 4.1: Datasets used in the analysis

Dataset	Description
Connected Nations (Ofcom)	Ofcom's Connection Nations report provided the evidence on the key outcomes of interest for the analysis including broadband availability and average download speeds at a postcode level (which gives an indication of take-up of available speeds) between 2012 and 2021. The data provided a snapshot of local connectivity in June of each year up to and including the 2016 release. The 2017 release provided a snapshot in May of that year and the 2018 to 2021 releases providing a snapshot for September of the relevant year.
Speed and Coverage Templates (SCTs)	Details of eligible ('white') postcodes and the postcodes included in the build plans of local schemes are generally captured within Speed and Coverage Templates (SCTs) that are completed by providers as part of the tendering exercise. BDUK supplied Ipsos with all available SCTs, which covered almost all local schemes that had been contracted under Phase 1, 2 and 3 by September 2021.
C3 reports	Claimed delivery of premises upgraded are reported to BDUK by contractors in a 'C3 report.' The C3 report captures the address of each premise the contractor claimed they had upgraded and provides predicted download and upload speeds. C3 reports to September 2021 gave details of some 8m premises that were claimed to have been upgraded by providers.
Network infrastructure	BDUK supplied a range of other data describing the pre-programme characteristics of postcodes in the UK which served as control variables for the analysis. These primarily described the characteristics of local networks in 2013 in terms of factors likely to influence the costs of upgrading serving cabinets or the final speeds attained.
Area level characteristics	Measures of local population density, the size of the working age population and population aged 65 percent were taken from the 2011 Census. Measures of gross weekly earnings, unemployment, and employment were derived from the Annual Survey Hours and Earnings and the Annual Population Survey respectively.
GBVS and LFFN	BDUK made available details of the delivery of the Gigabit Voucher Scheme and Wave One LFFN projects. This allowed the analysis to control for the possible influence of these parallel schemes in the analysis.

4.2 Evaluation design issues

4.2.1 Key outcomes

The key outcomes of interest for the following analysis are summarised in the following table. The outcomes cover a mix of supply and demand side variables.

Table 4.2: Key outcomes

Outcome	Overview
NGA coverage	The percentage of premises able to access broadband through NGA technologies – wireless, FTTC, FTTP and Wireless. This the primary outcome measure defined for the evaluation in the State aid evaluation plan agreed between DCMS and the European Commission.
Superfast coverage	The percentage of premises able to access speeds of 30Mbit/s. NGA technologies are capable of delivering superfast speeds but will not always do so (for example, if the premises is too far from the cabinet). This measure more closely aligns with the objectives of the programme.
FTTP coverage/Gigabit capable coverage[20]	Phase 3 of the programme prioritised technologies capable of delivering gigabit per second speeds which has concentrated investment in FTTP delivery. Connected Nations data for 2020 and 2021 provided information on gigabit capable coverage, while in prior years it provided details on FTTP coverage. This broader measure includes non-FTTP technologies capable of gigabit speeds. Consultation with BDUK and Ofcom indicated that Virgin Media gigabit capable coverage accounted for much of the difference between the FTTP coverage and gigabit capable coverage (and the roll-out of Virgin Media coverage did not begin in large volumes until 2020). As such, an assumption has been made that FTTP and gigabit capable coverage were equivalent before 2020.
Number of connections of 30Mbit/s or higher	The number of households or businesses taking up a 30Mbit/s connection is a primary outcome measure defined in the State aid evaluation plan agreed between DCMS and the European Commission.
Average download speed of connections	The average download speed of connections is a secondary outcome measure describing the effect of the programme on actual speeds used by households and businesses.
Maximum download speed of connections	This describes the maximum capacity of the connection taken by households or businesses and is a secondary outcome measure describing how the connectivity made available through the programme is used.
Average upload speed of connections	The average upload speed of connections is a secondary outcome measure describing the effect of the programme on actual speeds used by households and businesses.

4.2.2 Definition of the treatment and comparison group

A credible assessment of the impact of the Superfast Broadband Programme requires the selection of appropriate comparison group of postcodes or areas that did not receive BDUK investment, to enable an assessment of what may have happened in the absence of the programme. This is problematic for the following reasons:

- **Targeting at white areas**: Investment was targeted at white premises where commercial operators stated they had no plans to roll-out superfast broadband coverage without public subsidies. As such, 'grey' and 'black' premises or postcodes are unlikely provide a suitable counterfactual as they had been deemed commercially viable, and therefore were more likely to have received superfast coverage in the absence of the Programme. The inclusion of these areas in a comparison group would understate the impact of the Programme. Drawing the comparison group from the population of postcodes that were deemed 'white' in the OMRs but were not included in the build plans of Phase 3 schemes helps ameliorate this problem.

- **Supplier choice:** However, selecting the comparison group from white postcodes not included in build plans does have some caveats. Suppliers were largely free to choose which white premises

[20] A request for information on Virgin Media gigabit capable coverage in 2019 has been submitted to check our understanding.

were targeted from those identified in the OMR. It is reasonable to assume that suppliers selected those locations that were most commercially viable to maximise their returns. White postcodes not included in the build plans of Phase 3 contracts are likely to differ in systematic ways to those that benefitted from subsidised upgrades, and in ways that may be correlated with the outcomes of interest. Those premises in white areas that did not benefit from BDUK investment may have been the hardest to upgrade profitably, and the least likely to have received superfast coverage in the absence of the Programme. Basic comparisons between areas benefitting from the Programme and other white postcodes will likely overstate the impact of the Programme. Addressing these issues requires the selection of appropriate analytical methods that control for both observable and unobservable differences between these two groups of areas.

- **Crowding out:** If there are potential limits to the level of resources that suppliers can bring to bear in the delivery of the programme, resulting from either availability of skilled labour or, for smaller suppliers, credit market constraints, then the delivery of the superfast programme may have had negative impacts outside of white areas. As such, there is a risk of upward bias in any estimates of the impact of the programme on infrastructure that draw on areas that did not receive BDUK investment, since superfast coverage would have otherwise been higher in the comparison group.

The State aid evaluation plan defined the treatment as postcodes that have been included in Phase 3 build plans and had at least one premise upgraded by the end of September 2021. While this approach enables an assessment of the effects of the programme on areas that have benefitted from subsidised upgrades, this also introduces possible biases driven by unobserved differences between those areas that benefitted from early delivery and those benefitting at a later stage. Such an approach will also fail to capture any effects of the programme on areas that were yet to benefit from subsidised upgrades (e.g. delaying superfast rollout). To address this, all analyses have also been completed using an expanded definition of the treatment group to include all postcodes within build plans for Phase 3.

Given the complexities involved, several methods have been applied to explore the effects of the programme which are outlined in detail below (including the methods identified in the State aid evaluation plan and some additional methods deployed to enhance the robustness of those results).

4.3 Simple difference-in-differences

As described in the State aid evaluation plan, a simple difference-in-difference approach was used to establish an estimate of the change in broadband availability. This approach takes the difference between the weighted mean[21] of the outcomes of interest (i.e. the percentage of premises with NGA, superfast and FTTP/Gigabit capable coverage) before and after intervention across the control and treatment groups to give the change in coverage in NGA white areas due to intervention.

$$\Delta outcome_{intervention1621} = (outcome_{T21} - outcome_{T16}) - (outcome_{C21} - outcome_{C16})$$

The percentage change in coverage between 2016[22] and 2021 attributable to the programme is equal to the difference in outcomes in 2021 and 2016 for postcodes benefitting from the programme $(outcome_{T21} - outcome_{T16})$ and the comparison group of postcodes that were eligible in Phase 3 but not included in build plans $(outcome_{C21} - outcome_{C16})$[23].

[21] Weighted by total premises per postcode

[22] This is 2017 for FTTP given lack of inclusion of this variable in the 2016 Connected Nations data

[23] Note that T subscript denotes the Treatment Group, and the C subscript denotes the Control Group.

The difference-in-difference model is robust to unobserved but time invariant differences between postcodes that could bias results. However, estimates may be biased by unobserved but time varying differences between areas (the 'parallel trends' assumption). As noted in the preceding section, areas included in Phase 3 build plans saw a different pattern of investment in coverage over time relative to other white postcodes, which could lead to possible distortions in the results. As such, the results provided below are presented as a reference case for more robust methods explored below.

The simple difference-in-difference analysis showed:

- **Postcodes benefitting from subsidised upgrades:** These models indicated that Phase 3 delivery increased the percentage of premises covered by NGA, superfast and Gigabit capable by eight, 47 and 56 percentage points respectively on those postcodes that had benefitted from subsidised coverage by September 2021.

  In terms of take-up measures, the Programme was associated with no significant impact on the number of superfast connections, though effects on the maximum download speeds of connections were positive (around 59Mbps on average). This suggests that while the programme did not increase the overall numbers of households taking faster connections by September 2021, those that have taken faster connections have been able to obtain faster speeds. As highlighted previously, given that delivery was concentrated in 2019 and 2020, it is premature to draw any firm conclusions on the impact of the programme on take-up.

- **Postcodes in Phase 3 build plans:** The estimated impact of the Programme was smaller when the models were applied to all postcodes in the build plans of Phase 3 schemes (reflecting that not all postcodes would have benefitted from subsidised coverage at this time). The estimated impacts on the percentage premises covered by NGA, superfast, and Gigabit capable were 3.2, 30.6 and 30.5 percentage points respectively.

Table 4.3: Estimated impact of Phase 3 schemes on coverage and take-up, simple difference-in-difference results

	Change in outcome between 2016/17[24] & 2021			Change in outcome between 2016/17[25] & 2021		
Outcome	Other white postcodes	Treatment group	Estimated impact	Other white postcodes	Treatment group	Difference
Treatment group	Postcodes delivered to by September 2021			All postcodes in Phase 3 build plans		
Coverage outcomes						
NGA availability (% of premises)	16.8	24.6	7.8***	17.1	20.3	3.2***
Superfast availability (% of premises)	21.2	67.8	46.6***	21.2	51.9	30.6***
Gigabit capable availability (% of premises)	9.1	65.3	56.2***	9.1	39.6	30.5***
Take-up outcomes						
Average download speeds of connections (Mbps)	28.4	29.1	-0.7	28.4	21.4	-7.0***
Maximum download speeds of connections (Mbps)	59.4	94.1	34.7***	33.6	46.5	12.9***
Average upload speeds of connections (Mbps)	6.3	12.2	5.9***	9.7	12.2	2.5***
Number of connections with download speed of 30Mbps+	7.5	6.4	1.2***	7.5	5.8	-1.7

*Source: Ipsos analysis; *** represents differences significant at 99 percent, ** at 95 percent and * at 90 percent*

4.4 Regression based difference-in-differences

The specification defined in the State aid evaluation plan does not account for differences in the observable characteristics of areas, which could bias results. As highlighted above, suppliers were expected to prioritise those postcodes that could be made commercially viable with less subsidy. As a result, the findings in the preceding section could overstate the impact of the programme. An equivalent regression-based difference-in-differences[26] approach was also adopted that controlled for observable differences between postcodes using a vector of control variables as follows:

$$\Delta outcome_i = \beta_0 + \beta_1 TD + \boldsymbol{\beta x_i} + \epsilon_i$$

In this specification, the change in the outcome of interest between 2016 and 2021 for postcode i ($\Delta outcome_i$) is determined by a dummy variable, TD, (taking the value of 1 if the postcode was in the treatment group and 0 otherwise) in addition to a vector of control variables, $\boldsymbol{x_i}$ capturing the baseline characteristics of the postcodes and pre-programme trends in connectivity (presented below).

[24] 2017 for FTTP

[25] ibid

[26] The equation shows the 'first-difference' version of the difference-in-difference approach.

4.4.1 Control variables

The data available allowed us to consider the following characteristics of postcodes prior to the roll-out of the programme in 2013/14 and some coverage and take-up characteristics in 2016 (with variables selected based on evidence regarding the key determinants of commercial viability based on relevant academic literature[27] and consultations with BDUK officials):

- **Connectivity in 2012 and 2016:** Pre-programme levels of connectivity were considered by including observations of NGA access in all years from 2012 to 2016. Superfast coverage from 2014 to 2016 was also included as a matching variable.

- **Competition:** The number of network providers operating in the postcode in 2012 and 2016. This inclusion was driven by the apparent tendency of Phase 3 suppliers to avoid areas where NGA penetration (and by implication depth of local competition) was higher.

- **Percentage of postcodes in the LA and the Output Area with NGA access in 2012 and 2013:** In Phase 3, the data suggested that suppliers tended to avoid postcodes with high levels of NGA penetration. The expectation was that postcodes located in areas with local authorities and neighbourhoods with low NGA coverage in 2012 and 2013 would have been more likely to have been included within the build plans of local schemes, on the assumption that the Open Market Review process was effective in revealing the commercial plans of providers.

- **Line length from the exchange to the cabinet to the postcode in 2013:** The length of the line between the serving exchange and the postcode will partly determine the costs associated with enabling superfast broadband speeds, with costs increasing with the overall length of the line. The expectation was that postcodes benefitting from BDUK investment would be associated with longer line lengths than 'grey' and 'black' postcodes, but shorter line lengths than white postcodes that were not included within the build plans of local schemes.

- **Number of premises with exchange only lines in 2013:** Premises that are connected directly to the exchange will cost more to enable with superfast broadband speeds as this requires the installation of a new cabinet. The prior expectation was that postcodes with a higher number of premises with exchange only lines would be less likely to be included within the build plans of local schemes owing to these additional costs.

- **Delivery points at the serving cabinet and the serving exchange:** The attractiveness of upgrading available broadband services to at least superfast speeds will also be linked to the number of premises that benefit from the upgrade. As such, it was anticipated those postcodes with fewer delivery points at the serving cabinet and exchange would be less commercially attractive and carry a lower likelihood of being included within the build plans of local schemes, relative to other white postcodes.

- **Whether the postcode was in the Virgin Media footprint in 2013:** Data was made available on whether the postcode was within the Virgin Media footprint in 2013. The availability of Virgin Media at a postcode could reduce the likelihood that it was included in local schemes – signalling the presence of a competitor and reducing the commercial benefits associated with providing upgraded services. However, when comparing white postcodes, where Virgin Media may have had no immediate plans to roll out superfast broadband services, competing providers may see an attraction

[27] E.g. Ahlfeldt et al (2014) Speed 2.0: Evaluating Access to Universal Digital Highways

in providing superfast to the postcodes to enable them to gain a competitive advantage, increasing the likelihood that the postcode was included in the build plans for local schemes.

- **Estimated cost to upgrade the serving cabinet or exchange only lines:** BDUK developed estimates of the cost of upgrading the cabinets or exchange only lines in 2013 to support the resource allocation process. The expectation was that those cabinets with higher predicted upgrade costs (or higher upgrade costs per premises upgraded) would be less likely to be included within the build plans for local schemes (or at least those that involved higher upgrade costs per premises upgraded).

- **Population density:** The likelihood that a postcode was upgraded was also thought to be linked to the density of the local population, with denser eligible areas the most likely to be included within the build plans of local schemes. This was measured using information from the 2011 Census describing the size of the resident population at an Output Area level.

- **Age of population:** The size of the resident population of working age and aged 65 and over was included to provide measures of overall potential demand for superfast broadband services.

- **Other factors influencing demand:** Demand for superfast broadband services was also assumed to be linked to the characteristics of the local economy. Information on gross weekly earnings, employment rates and unemployment rates were included to provide these types of measure.

- **GBVS and LFFN:** A supplementary set of analyses were also undertaken to control for the delivery of parallel programmes that may have also contributed to changes in connectivity locally. This included controls for the number of GBVS vouchers awarded to upgrade other premises in the relevant output area to FTTP, and proximity to the fibre rings or public sector buildings upgraded by Wave One LFFN pilot projects[28]. It should be noted that there are other BDUK (e.g. Wave 2 and 3 LFFN pilots) and locally funded programmes (e.g. broadband voucher schemes administered by Local Enterprise Partnerships) that could produce similar results to the Superfast Broadband Programme. Data on the delivery of these schemes could not be compiled for the purposes of this study (and as such, there is a residual risk that some outcomes attributed to the Superfast Broadband Programme were the results of parallel programmes).

4.4.2 Results

The results using a regression approach are presented in Table 4.4 below. The results of models without control variables were identical to those obtained using simple differences-in-differences. Controlling for the pre-programme characteristics of postcodes led to smaller estimates of the impact of the programme, suggesting that the results of the simple difference-in-difference analyses were biased upwards (as expected):

- **Coverage on postcodes benefitting from subsidised upgrades:** The results suggested that the Phase 3 schemes increased the share of premises covered by NGA, superfast and FTTP/Gigabit capable technologies by 4.1, 43.4, and 51.7 percentage points respectively (in those postcodes benefitting from subsidised upgrades by September 2021). As with the preceding analysis, the effect of the programme on FTTP availability was larger than for superfast availability (implying that some

[28] These controls took the form of dummy variables denoting whether or not a postcode was located within 50m, 100m, 500m or 1km of a GBVS voucher or an LFFN intervention area (in turn defined as a postcode within 1km of planned LFFN build).

premises receiving FTTP coverage would have otherwise received superfast coverage through other technologies).

- **Coverage on all postcodes in the build plans of Phase 3 SCTs:** The findings with all postcodes in build plans as the treatment group were similar. These suggested that the share of premises covered by NGA, superfast and FTTP/Gigabit capable technologies increased by 2.1, 29.5, and 28 percentage points respectively in these areas.

- **Speeds and take-up:** The results this time round indicated that the programme has had a positive impact on several take-up measures. Maximum speeds and average upload speeds in particular indicated increases.

The addition of controls for the GBVS and LFFN did not materially alter the estimated impacts, indicating that the estimated impacts are not confounded by the delivery of parallel schemes. Additionally, most models were estimated using Ordinary Least Squares. This could produce biased results for those outcomes that were bounded at zero and one (e.g. NGA availability cannot exceed 100 percent and cannot fall below zero percent). Robustness checks were completed by estimating models (Model 4 and Model 8) with a Tobit specification that allowed for censoring at 0 and 100. Results from these models did not suggest that OLS was biased in this case.

Table 4.4: Estimated impact of Phase 3 schemes on coverage and take-up, regression-based difference-in-difference results

Outcome	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Treatment postcodes	Postcodes delivered to by Sep. 2021				All postcodes in Phase 3 build plans			
Modelling approach	OLS	OLS	OLS	Tobit	OLS	OLS	OLS	Tobit
Postcode controls	No	Yes	Yes	Yes	No	Yes	Yes	Yes
LFFN/GBVS controls	No	No	Yes	Yes	No	No	Yes	Yes
Number of observations	60,436	21,348	21,348	21,348	117,120	109,514	109,514	109,514
Adjusted R-squared	0.0111	0.7181	0.7031	0.5908	0.0022	0.6159	0.6913	0.4982
NGA availability (% of premises)	7.6***	5.2***	5.2***	4.1***	3.2***	2.3***	2.2***	2.1***
Superfast availability (% of premises)	47.5***	45.8***	45.8***	43.4***	31.3***	29.9***	29.9***	29.5***
Gigabit capable availability (% of premises)	57.3***	52.1***	52.2***	51.7***	31.2***	28.9***	28.9***	28.0***
Average download speeds of connections (Mbps)	-0.8***	-0.2	-0.2	n/a	-7.8***	-3.9***	-3.8***	n/a
Maximum download speeds of connections (Mbps)	60.7***	58.9***	59.2***	n/a	12.1***	11.5***	11.4***	n/a
Average upload speeds of connections (Mbps)	6.0***	5.6***	5.7***	n/a	3.4***	3.1***	3.1***	n/a
Number of connections with download speed of 30Mbps+	1.2***	0.6***	0.8***	n/a	-0.6	-0.4	-0.4	n/a

*Source: Ipsos analysis; *** represents differences significant at 99 percent, ** at 95 percent and * at 90 percent*

*.

4.5 Difference-in-difference with matched samples

The preceding set of analyses controlled for observable differences between the areas benefitting from the Programme. These analyses were refined further by selecting a comparison group of white postcodes that were observationally equivalent to those included in the build plans of Phase 3 schemes. This was achieved using a propensity score matching (PSM) matching approach. This involved matching postcodes in the treatment and control groups based upon their characteristics in the years before 2016. This was implemented by:

- Developing statistical models that compared the characteristics of white postcodes that were and were not included in the build plans of local schemes and predict the likelihood that each postcode was included in a scheme.
- White postcodes that were not included in the build plans of Phase 3 schemes – but shared a similar predicted likelihood of being included to those postcodes that were addressed by those build plans - were considered to be 'matched' and formed part of the comparison group.
- Postcodes that did not feature in the build plans of local schemes and did not share a similar likelihood of inclusion within the build plan of a local scheme were dropped from the sample and did not form part of the comparison group.

4.5.1 Control variables

This approach offers an unbiased estimate of the impact of the programme if it is possible to control for all factors that influenced the inclusion of a postcode within the build plan of a Phase 3 scheme. Postcodes were matched on the same vector of control variables described in Section 4.4.1.

4.5.2 Matching models

Propensity scores were generated by applying a probit model that sought to explain the likelihood a given postcode was included in the build plan of a Phase 3 scheme on the vector of control variables described in section 4.4.1 above[29]. These models were estimated with and without controls for the average and maximum downloads speeds of connections (owing to the large amount of missing data on these variables for 2012 and 2013).

The results of the probit models associated with the two selected matching models largely confirmed expectations regarding how the observable characteristics of postcodes would influence their inclusion within local schemes. There was a relatively high degree of consistency in the direction and size of the estimated coefficients when information on historic average download speeds was also included as a matching variable.

4.5.3 Quality of the matched sample

Matching was completed using a nearest neighbour technique in which each postcode in the build plans of Phase 3 schemes were matched to the postcode in the comparison sample with the closest propensity score[30]. Common support was imposed by dropping any postcode from the comparison sample that had a propensity score that was higher than the highest – or lower than the lowest – propensity score

[29] The model took the form: $\Delta outcome_i = \beta_0 + \beta_1 TD + \boldsymbol{\beta x_i} + \epsilon_i$

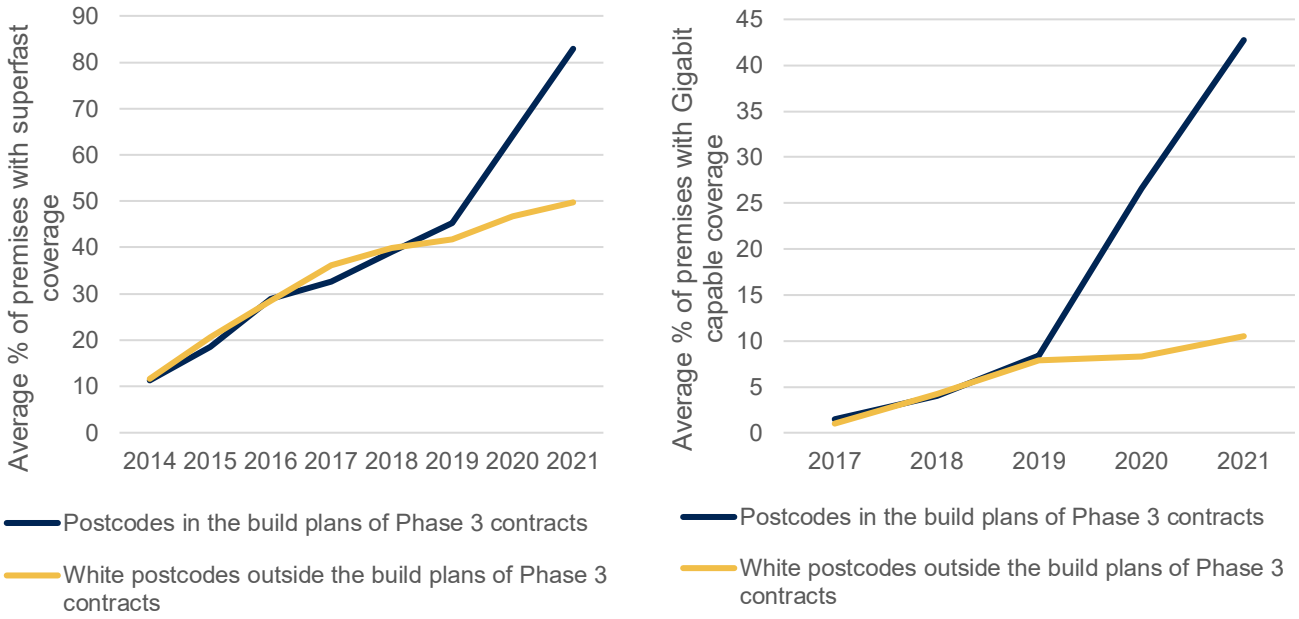
[30] This took the form of a Probit model: $\Pr(Yi = 1|Xi) = \phi(Xi\beta)$. In this model, Y is a binary indicator describing whether postcode i was included within the build plan of a local scheme (1 = yes, and 0 = no) and X is a vector of factors describing the characteristics of the postcode that are thought to influence its inclusion in the scheme.

associated with postcodes included within the build plans of Phase 3 schemes. Individual postcodes in the comparison sample could form a match with multiple postcodes that received BDUK subsidies.

An overview of the resultant matched samples is provided in Table 4.5 below. The matching approach reduced the mean standardised bias (the average percentage differences in the characteristics of the treatment and the comparison sample) to between 1.2 and 3.9 percent (from between 13.8 and 35.6). There were limited significant differences between the treatment and comparison samples on most characteristics included in the matching models, however the models were not fully effective in eliminating all observable differences between the treatment and comparison samples. The models tended to produce a comparison sample with a larger number of delivery points in the serving exchange and in the serving cabinet.

The charts below illustrate the evolution of superfast and gigabit capable coverage over time for the postcodes in the build plans for Phase 3 relative to those in the matched comparison area. This clearly demonstrates the success of the matching algorithm in reducing the differences between areas pre-intervention (and illustrates the impact of the programme on superfast and gigabit capable coverage).

Figure 4.1: Changes in superfast broadband (at least 30Mbit/s) and Gigabit capable coverage (% of premises), areas in Phase 3 build plans and matched white postcodes, 2014 to 2021



Source: C3 reports, Ofcom Connected Nations, Ipsos analysis.

As illustrated in the table below, few postcodes dropped from the matching implying that the postcodes within each of the groups were relatively similar overall. The models including take-up and speed outcomes as controls performed more effectively with fewer dropped postcodes in the treatment group.

Table 4.5: Overview of Characteristics of Matched Samples

Treatment group	Postcodes delivered to by September 2021						Postcodes in the build plans of Phase 3 schemes					
Controls included	**No speed controls**			**Speed controls included**			**No speed controls**			**Speed controls included**		
No. of treated postcodes in matched sample	35,564			16,372			61,493			25,938		
Number of unmatched postcodes	109			49			190			84		
Mean standardized bias (pre-match)	37.4			21.6			27.7			14.5		
Mean standardized bias (post-match)	4.1			2.9			1.8			1.3		
Variable	Treated	Control	Sig.	Treated	Control	Sig.	Treated	Control	Sig.	Treated	Control	Sig.
Number of suppliers in postcode (2012)	2.18	2.22	*	2.30	2.33		2.42	2.44	**	2.46	2.48	**
Number of suppliers in postcode (2016)	2.40	2.43	*	2.49	2.51		2.48	2.48		2.52	2.52	
Superfast % of premises (2014)	8.01	8.15		6.73	6.63		11.80	11.27	**	9.87	9.47	*
Superfast % of premises (2015)	12.21	13.18	*	13.16	12.54		18.87	17.62	***	20.97	19.61	***
Superfast % of premises (2016)	23.12	26.42	***	25.73	24.91		28.97	28.02	***	34.01	32.79	**
NGA % or premises (2012)	0.16	0.17	**	0.14	0.15		0.16	0.16	*	0.12	0.12	
NGA % or premises (2013)	0.26	0.31	**	0.23	0.28	***	0.26	0.27	***	0.20	0.21	**
NGA % or premises (2014)	0.34	0.38	***	0.33	0.37	***	0.35	0.35	*	0.32	0.33	*
NGA % or premises (2015)	0.60	0.62	***	0.61	0.61		0.66	0.67	**	0.67	0.68	*
NGA % or premises (2016)	0.71	0.74	**	0.71	0.73	*	0.75	0.75		0.77	0.77	
% of postcodes in LA with NGA, (2013)	0.40	0.41	***	0.41	0.41		0.42	0.42	*	0.41	0.41	
% of postcodes in LSOA with NGA, (2013)	0.29	0.32	***	0.28	0.31	**	0.28	0.29	**	0.23	0.24	*
Line Length (m)	8.14	8.14		8.06	8.10	*	8.08	8.07		7.94	7.96	
Final speed	6.60	6.47		7.02	7.00		6.85	7.01	***	7.41	7.50	*
Premises with EO lines 2013	2.32	2.25		3.71	3.47		2.30	2.40	*	3.83	3.89	
Delivery points at serving exchange	6788.20	7767.81	***	6776.06	7646.12	***	6540.95	6635.81	*	6125.51	6249.74	
Delivery points at serving cabinet	220.23	232.05	***	238.43	256.47	***	254.81	255.57		272.98	274.40	
Virgin Media availability	0.00	0.00		0.00	0.00		0.01	0.01	*	0.00	0.00	
Estimated Upgrade Cost (£)	66829.38	67346.52		68695.98	69364.08		68922.42	68626.62	*	70372.86	69970.98	

Cost Per Premises Upgraded	358.60	348.59		333.56	316.04	*	340.10	338.11		290.63	280.82	**
Working Age Population	202.03	205.23	**	202.06	208.10	**	180.40	183.57	***	179.78	184.05	***
Population Aged 65 and Over	66.45	68.36	***	67.03	66.71		58.64	59.39	***	59.72	61.13	***
(Log) Population Density	4.39	4.45	*	4.75	4.75		4.62	4.63		5.09	5.08	
(Log) Premises Density	3.80	3.89	*	4.15	4.16		4.06	4.07		4.51	4.51	
Gross Weekly Wages (in LA)	506.09	501.98	***	510.53	508.93		513.76	513.02	*	513.00	510.62	**
Employment Rate (in LA)	76.09	76.01		76.13	76.04		75.71	75.82	**	75.43	75.58	**
Unemployment Rate (in LA)	6.28	6.12	***	6.26	6.13	*	6.51	6.43	***	6.58	6.52	*
No. prems with superfast available (2014)	1.67	1.63	***	1.53	1.49		2.60	2.47	**	2.37	2.28	
No. prems with superfast available (2015)	2.37	2.38		3.02	2.91		3.87	3.59	***	5.07	4.85	
No. prems with superfast available (2016)	3.95	4.13		5.59	5.28		5.53	5.31	**	7.93	7.73	
No. superfast connections (2016)				1.14	1.00	*				1.66	1.63	*
No. superfast connections (2015)				0.65	0.60					0.94	0.93	
No. superfast connections (2014)				0.23	0.23					0.30	0.30	
Average Download Speeds (2012)				5.19	5.20					5.67	5.65	
Maximum Download Speeds (2012)				8.46	8.38					9.15	9.16	
Average Download Speeds (2013)				5.75	5.78					6.35	6.35	
Maximum Download Speeds (2013)				9.98	10.15					10.68	10.79	*
Average Download Speeds (2014)				7.00	7.05					7.81	7.84	
Maximum Download Speeds (2014)				14.47	14.83					16.01	16.24	
Average Download Speeds (2015)				8.57	8.47					9.77	9.78	
Maximum Download Speeds (2015)				19.09	18.91					22.50	22.52	
Average Download Speeds (2016)				11.08	10.60	**				13.08	13.09	
Maximum Download Speeds (2016)				25.36	24.21					30.86	30.99	
Average Upload Speeds (2014)				0.89	0.87					0.97	0.97	
Average Upload Speeds (2015)				0.89	0.87					0.97	0.97	
Average Upload Speeds (2016)				1.55	1.53					1.81	1.76	**

*Source: Ofcom Connected Nations, C3 Reports, SCTs, Ipsos analysis; *** represents differences significant at 99 percent, ** at 95 percent and * at 90 percent*

4.5.4 Results

A matching approach will only be effective in providing an unbiased assessment of the impact of the Programme if they capture all factors that could influence both the selection of postcodes into BDUK funded schemes and the likelihood that they will receive enhanced broadband connectivity. There may be other factors influencing the cost of installation that were not controlled for, e.g. local topography. Additionally, there are potentially unobserved features of postcodes that may be correlated with both their inclusion in the Programme and the likelihood that superfast broadband coverage would have come forward without public subsidy.

To account for unobserved (but time invariant) differences between the matched treatment and comparison group, the matched samples generated above were used to implement the difference-in-difference models described in section 4.3. The key results are set out in Table 4.6. However, there was very little difference in the estimated results to those associated with the difference-in-difference models described above (implying that the preceding results were not biased by observed differences between the two groups of postcodes).

Table 4.6: Estimated impact of Phase 3 schemes on coverage and take-up, regression-based difference-in-difference results

	Model 9	Model 10
Treatment postcodes	Postcodes delivered to by September 2021	Postcodes in the build plans of Phase 3 schemes
Model specification	OLS	OLS
Postcode Controls	Yes	Yes
LFFN/GBVS Controls	Yes	Yes
Matched Sample	Yes	Yes
Number of observations	18,763 to 47,382	33,744 to 84,623
Adjusted R-squared	0.012 to 0.532	0.001 to 0.611
Coverage outcomes		
NGA availability (% of premises)	4.4***	2.0***
Superfast availability (% of premises)	43.5***	28.3***
Gigabit capable availability (% of premises)	50.2***	28.4***
Take-up outcomes		
Average download speeds of connections (Mbps)	-0.1	-2.4***
Maximum download speeds of connections (Mbps)	52.6***	10.0***
Average upload speeds of connections (Mbps)	4.4***	3.0***
Number of connections with download speed of 30Mbps+	3.9***	-0.2

*Source: Ipsos analysis; *** represents differences significant at 99 percent, ** at 95 percent and * at 90 percent*

4.6 Longitudinal panel models

The difference-in-difference models outlined in sections 4.4 and 4.5 account for observed differences between postcodes included in the build plans of Phase 3 schemes and the comparison group of other white postcodes. The models also account for unobserved but time invariant differences between the two groups. A final set of supplementary set of analyses were developed to probe the robustness of the results further by accounting for unobserved but time specific shocks that could affect all areas (the COVID-19 pandemic could be an example of this, if it prompted consumers to upgrade their connections to enable remote working).

This was achieved by exploiting the longitudinal nature of the data available using the following panel model specification:

$$outcome_{it} = \beta_0 + \beta_1 CP_{it} + \theta t + \alpha_i + \gamma_t \ + \epsilon_i$$

Here, the outcome for postcode i in year t is determined by the cumulative number of premises upgraded in the area by year t (CP_{it}) with the effect given by β_1. This model allows for the inclusion of both entity fixed effects ($\boldsymbol{\alpha_i}$) which account for any time invariant observed and unobserved characteristics of postcodes as well as time fixed effects (γ_t) that account for any time specific shocks influencing connectivity or take-up across all areas. In addition, the equation includes time trends at the national level (t).

The specification of these models captures the relationship between the timing of subsidised upgrades and changes in coverage. As such, the results can be compared to those preceding analyses focusing on areas that benefitted from subsidised coverage but not to those that explore the impact of the programme on all postcodes included in the build plans of Phase 3 schemes. The apparent effects of Phase 3 in delaying the availability of superfast coverage for some premises is explored in more detail in the following chapter.

The comparison group for these analyses comprises of postcodes that were eligible for Phase 3 funding but weren't upgraded by September 2021. In addition, postcodes updated in later years form a part of the control group for those upgraded in earlier years with them switching to the treatment group in the year the postcode was upgraded.

4.6.1 Results

Table 4.7 below outlines the findings of the analyses. The definition of the treatment variable differs to those employed in the preceding analyses (which used a dummy variable classifying whether the postcode was upgraded or not). As results, the regression coefficients are not directly comparable – effects are expressed as the average effect per premises upgraded per postcode. The findings indicated:

- **NGA, superfast and Gigabit capable availability:** The panel models showed that NGA, superfast and FTTP/Gigabit capable coverage increased in response to the delivery of subsidised coverage. For each premises upgraded, the number of premises with NGA, superfast and gigabit capable availability rose by 0.40, 0.69 and 0.66 respectively in the most robust models, augmented to control for time-specific shocks affecting all areas, national trends, and the delivery of parallel programmes. The findings can be interpreted as a direct measure of additionality (i.e. the share of premises upgraded that would not have had enhanced coverage in the absence of the Programme).

- **Take-up:** The results showed a similar pattern of findings for take-up measures as preceding analyses. These findings indicated that the Programme had no significant effect on the number of superfast connections, however, for each premise upgraded on a postcode, average speeds taken up increased by a negligible amount whilst maximum speeds rose around 48Mbits/s.

Table 4.7: Estimated impact of subsidised coverage on superfast availability and take-up – Phase 3 2016 to 2021

Outcome	Model 11	Model 12	Model 13	Model 14	Model 15
Type	FE	FE	FE	FE	Tobit
Postcodes included	All white postcodes				
Time fixed effects	No	Yes	Yes	Yes	Yes
Time trends	No	No	Yes	Yes	Yes
GBVS controls	No	No	No	Yes	Yes
Number of observations	418,374 to 1,044,703	418,374 to 1,044,703	418,374 to 1,044,703	418,374 to 1,044,703	418,374 to 1,044,703
Adjusted R-squared	0.022 to 0.160	0.082 to 0.227	0.143 to 0.244	0.074 to 0.255	0.113 to 0.383
Coverage outcomes (effects per premise upgraded per postcode)					
Number of premises with NGA access	0.48***	0.48***	0.49***	0.40***	0.48***
Number of premises with superfast access	0.71***	0.71***	0.71***	0.69***	0.71***
Number of premises with Gigabit capable availability	0.69***	0.69***	0.69***	0.66***	0.69***
Take-up outcomes (effects per premise upgraded per postcode)					
Average download speed of connections (Mbps)	0.11***	0.11***	0.11***	0.11***	0.11***
Maximum available speed of connections (Mbps)	48.02***	48.02***	48.02***	47.37***	48.02***
Average upload speeds of connections (Mbps)	0.42***	0.42***	0.42***	-	0.42***
Number of superfast connections	-0.01	-0.00	-0.00	-0.01	-0.01

*Source: Ipsos analysis; *** represents differences significant at 99 percent, ** at 95 percent and * at 90 percent*

4.6.2 Additionality over time

The results above only compare changes in coverage and premises receiving subsidised coverage within the same year. This may provide a misleading representation of impact for the following reasons:

- **Delayed coverage for areas likely to receive enhanced connectivity anyway:** The matching models suggested a possible effect whereby the programme may have delayed investment in superfast coverage in those postcodes that would have been likely to receive enhanced that investment anyway. Failing to allow for this possible effect could cause estimates of impact to be overstated.

- **Lagged effects:** Additionally, there may be recording lags in the data (with increases in maximum download speeds visible in the Connected Nations data up to 1 year following the installation of the technology). Failing to allow for these lagged effects would cause estimates of impact to be understated.

- **Acceleration effects:** There is also a possibility that part of the effect of the programme is to accelerate an area's access to faster broadband speeds, rather than enabling the area to access faster speeds on a permanent basis. This would imply higher rates of additionality in the short-term and lower rates of additionality in the longer-term.

These hypotheses were explored by introducing forward and backward lags of the treatment variable into the model as follows:

$$\Delta NGA_{it} = \gamma_1 \Delta C_{it+1} + \gamma_2 \Delta C_{it} + \gamma_3 \Delta C_{it-1} + \gamma_4 \Delta C_{it-2} + \gamma_5 \Delta C_{it-3} + \gamma_6 \Delta C_{it-4} + \theta \Delta t + \alpha^{L} \Delta t + \alpha^{T} + \alpha^{L} \alpha^{T} + \varepsilon_{it}$$

The results are set out in the table below and suggest that the scheme did have a negative effect on NGA, superfast and FTTP availability in the year before premises received subsidised coverage (equivalent to between 6 and 11 premises per 100 connections). This implies a small degree of initial localised crowding out. However, the estimates suggested that in the year following the delivery of subsidised coverage, 0.53 additional premises received NGA coverage per premises upgraded (53 percent additionality), 0.55 additional premises received superfast coverage per premises upgraded (55 percent additionality) and 0.77 additional premises received FTTP coverage per premises upgraded (77 percent additionality). The estimates below give overall additionality of 20, 40 and 57 percent over the four-year period for NGA, superfast and FTTP respectively.

The general pattern over time remains consistent across coverage types in the table below and this allows for the plotting of additionality over time. The results shown in the figure below imply a slowly decreasing level of additionality over time, up to five years after delivery in the overall results. This implies that the likelihood of an area being upgraded in the absence of the programme increases as time passes (implying that the programme has helped accelerate some commercial deployments as well as bring coverage to premises that may never have received enhanced broadband).

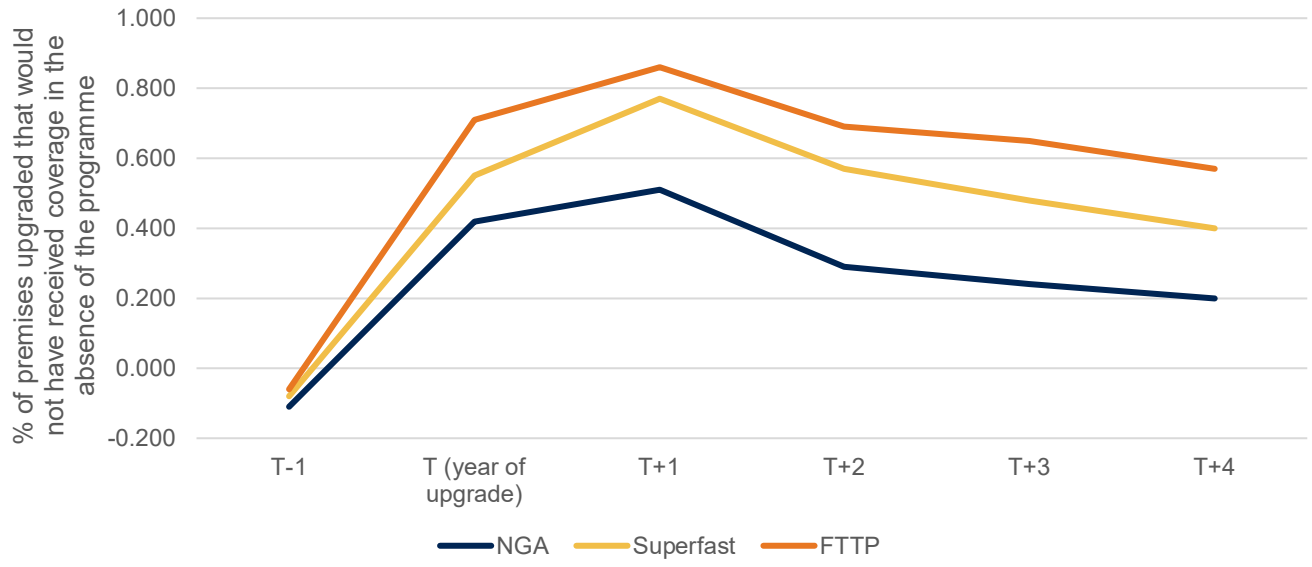
Additionally, estimates of the rate at which the programme accelerated commercial deployments are based on delivery in the first years of the programme (which may not be representative, given the large increases in delivery observed post 2019). As such, it is also plausible that additionality decays at a slower rate moving forward.

Table 4.8: Estimated Additionality Over Time – Longitudinal Panel Models

	NGA	Superfast	FTTP
Areas reaching 100% NGA coverage excluded?	Yes	Yes	Yes
Eligible areas excluded?	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes
2013 Output Area controls	Yes	Yes	Yes
Change in covered premises per premises receiving subsidised coverage (T-1)	-0.110***	-0.080***	-0.060***
Change in covered premises per premises receiving subsidised coverage (T)	0.530***	0.630***	0.770***
Change in covered premises per premises receiving subsidised coverage (T+1)	0.090***	0.220***	0.150***
Change in covered premises per premises receiving subsidised coverage (T+2)	-0.220***	-0.200***	-0.170***
Change in covered premises per premises receiving subsidised coverage (T+3)	-0.050***	-0.090***	-0.040***
Change in covered premises per premises receiving subsidised coverage (T+4)	-0.040***	-0.080***	-0.080***
Total effect 4 years post delivery	0.20	0.40	0.57
Observations	111,282	111,282	111,282
Adjusted R-Squared	0.47	0.54	0.51

*Source: Ipsos UK analysis; BDUK C3 reports & Ofcom Connected Nations; *** represents differences significant at 99 percent, ** at 95 percent and * at 90 percent*

Figure 4.2: Additionality estimates of Phase 3 NGA, superfast and FTTP coverage over time



Source: Ipsos UK analysis; BDUK C3 reports & Ofcom Connected Nations

4.7 Control group regression to predict counterfactual treatment group coverage

The second approach outlined in the state aid evaluation plan involves the application of regression techniques to the control group. This regression took the following form:

$$outcome2019_i outcome2021_i = \beta_0 + \boldsymbol{\beta x_i} + \epsilon_i$$

Where, the i subscript denotes observation number i, β_0 is a constant, $\boldsymbol{x_i}$ is a vector of explanatory variables which are believed to influence the outcomes in an area, $\boldsymbol{\beta}$ is a vector of the regression coefficients for those explanatory variables, and ϵ_i is an error term. A logistic regression function was used for NGA availability whilst Tobit models were used for outcomes bounded by 0 and 100 (the percentage of premises with superfast or FTTP\Gigabit capable coverage). A negative binomial function was utilised for the number of suppliers[31].

The regression coefficients are then applied to the treatment group postcodes to estimate what would have happened in the absence of the scheme (counterfactual). The difference between this estimated outcome and the actual observed outcome is then taken for the areas in the control group giving another estimate of the causal effect of the programme on the outcomes of interest.

4.7.1 Results

Application of the control group regression approach found largely similar results to the difference-in-difference with some exceptions where the treatment group comprised of only built to postcodes:

- **NGA, Superfast & Gigabit capable percentage availability:** These results were again similar to those presented in the difference-in-difference regression analysis above for these outcomes. Results for Gigabit capable coverage using this approach showed an additional 44.6 percentage points in FTTP/Gigabit capable coverage attributable to the programme in line with earlier findings above.

- **Take-up outcomes:** Application of the control group regression approach identified similar effects on all take-up outcomes.

[31] Negative binomial regression is a technique used for modelling count variables, usually for over-dispersed count outcome variables

Table 4.9: Control group coverage regression results – Phase 3 in 2021

	Counterfactual	Actual	Difference	Counterfactual	Actual	Difference
Treated postcodes	Delivered as of Sep 2021			All in build plans		
Coverage outcomes:						
Change in % NGA availability	87.6	90.8	3.2***	89.3	91.0	1.7*
Change in % SFB availability	51.4	92.3	40.9***	55.2	88.0	32.8***
Change in % Gigabit capable availability	13.8	57.0	43.2***	11.1	55.5	44.4***
Change in superfast enabled premises	10.6	12.1	1.5*	11.8	13.1	1.3*
Change in Gigabit capable enabled premises	3.1	7.4	4.3**	1.9	5.4	3.5*
Take-up outcomes:						
Change in average download speed (Mbps)	26.8	27.4	0.6*	27.4	27.5	0.1
Change in max download speed (Mbps)	69.5	103.2	33.7***	61.3	100.2	38.9***
Change in average upload speed (Mbps)	15.3	16.2	0.9**	13.4	15.4	2.0**
Change in number of superfast connections (Mbps)	5.7	4.7	-1.0***	5.5	4.9	-0.6*

*Source: Ipsos analysis; *** represents differences significant at 99 percent, ** at 95 percent and * at 90 percent*

4.8 Crowding out

The programme could have negative effects elsewhere if its delivery diverted scarce resources – such as skilled labour or capital – away from areas in which providers planned to install enhanced infrastructure without subsidy. However, positive effects (crowding-in) are also possible if the process of demand and cost recovery supported by the programme encouraged providers to make further or bring forward investments in superfast broadband infrastructure.

The level of crowding in or out was explored by assuming any effects of this nature were likely to occur at the local level. While telecoms operate national supply chains, the delivery of construction activity tends to be by local contractors (motivating this assumption). Additionally, it was assumed that the size of these effects would be linked to the volume of delivery in nearby white postcodes. This was operationalised using the following econometric model (a non-parametric distance-decay model):

$$NGA_{jt} = \alpha + \sum_{k=1}^{5} \gamma_k C_{kt} + \theta t + \alpha_i + \alpha_L t + \alpha_t + \alpha_L \alpha_t + \varepsilon_{it}$$

This model relates the number of premises covered by NGA, Superfast or FTTP on grey, black and otherwise ineligible postcodes in output area j in period t (NGA_{jt}) to the cumulative number of premises receiving subsidised coverage within distance bands (k) of increasing distance from area j (C_{kt}). Five distance bands were adopted for the purposes of the analysis at 10km intervals from the centroid point of the relevant LSOA[32] (0 to 10km, 10km to 20km, 20km to 30km, 30km to 40km, and 40km to 50km). The parameter γ_k captures the effect of each premises covered delivered in distance band k in period t on the number of premises on grey, black, and other ineligible postcodes covered by NGA, Superfast or FTTP. A positive coefficient is a signal of crowding-in and a negative coefficient is a signal of crowding out. The parameter θt accounts for time trends t the national level.

The model also allows for unobserved differences between areas that do not change over time (α_i), unobserved but time-specific shocks that affect all areas (α_t), unobserved trends at the local authority level ($\alpha^L t$) and unobserved and time-specific shocks at the local authority level ($\alpha_L \alpha_t$). As before, the model was specified in first differences removing the influence of any time invariant factors that might be correlated with the outcome:

$$\Delta NGA_{jt} = \sum_{k=1}^{5} \gamma_k \Delta C_{kt} + \theta \Delta t + \alpha_L t + \alpha_t + \alpha_L \alpha_t + \varepsilon_{it}$$

Any LSOAs without any grey, black, or otherwise ineligible postcodes were removed from the sample. Additionally, if NGA, Superfast or FTTP coverage reached 100 percent on all relevant postcodes within the Output Area, subsequent observations were removed from the sample from the following year (as by assumption there can be no crowding in or crowding out effects once 100 percent coverage is achieved).

4.8.1 Results

Overall, the analysis suggested the delivery of subsidised coverage led to a small reduction in NGA coverage in nearby areas in of crowding out in the 0 to 10km distance but also a small degree 10km to 20km and 20 to 30km away in the year of delivery. One year after, the opposite is true for areas 10 to 20km away and 20km to 30km. For superfast, the models implied a lower degree of crowding out in the year of delivery and one year after with effects only visible in the 10km to 20km band. There was no evidence of effects on FTTP coverage in nearby areas and overall the level of crowding out estimated is negligible in these models.

[32] Distances were calculated at an LSOA rather than a postcodes level to reduce the number of distances between pairs of areas that required calculation to produce the dataset needed for this analysis.

Table 4.10: Estimated Level of Crowding Out – up to 2019

	Model 1	Model 2	
	No lagged effects	Effect in year t	Effect in year t+1
		NGA	
0 to 10km	-0.0002***	-0.0002***	0.0002
10 to 20km	-0.0001	-0.0001*	0.0001*
20 to 30km	-0.0001**	-0.0003***	0.0004***
30 to 40km	0.0001***	0.0001***	0.0000
40 to 50km	0.0001	0.0000	0.0001
Total effect	-0.0002	-0.0001	
		Superfast	
0 to 10km	-0.0000	-0.0000	-0.0000
10 to 20km	-0.0001**	-0.0001**	-0.0001
20 to 30km	-0.0000	-0.0000	-0.0001
30 to 40km	0.0001	0.0001	0.0002
40 to 50km	0.0001	0.0001	0.0001
Total effect	-0.0001	-0.0001	
		FTTP	
0 to 10km	-0.0001	-0.0001	-0.0000
10 to 20km	-0.0000	-0.0000	-0.0001
20 to 30km	-0.0000	-0.0000	-0.0001
30 to 40km	0.0001	0.0001	0.0000
40 to 50km	0.0001	0.0001	0.0001
Total effect	-	-	

*Source: Ipsos UK analysis; BDUK C3 reports & Ofcom Connected Nations; ***, ** & * represent statistical significance at 99.9, 99 and 95 percent respectively*

4.9 Cost effectiveness

4.9.1 Initial expected public sector cost per covered premises

Data on the costs of delivering the Superfast Broadband Programme have been drawn from BDUK monitoring data and the outputs of the modelling exercise described in Section 6 (and used to support the cost-benefit analysis).

A total of £1.4bn of public sector funding appears to have been committed across Phase 3 contracts with a total of 531,029 contracted premises passed. This equates to an ex-ante gross public sector cost per premises covered of £2,636.

Table 4.11: Contracted cost per premises passed in Phase 3

Contract phase	Contracted public sector cost (£m)	Contracted premises passed	Gross public subsidy per gross premises passed (£)
Phase 3	1,400	531,029	2,636

Source: Ipsos UK analysis; Superfast Status Report, November 2022

4.9.2 Current expected (actual) public sector cost per covered premises

The table below provides estimates of the current expected public funding per covered premise by March 2021/22. The expected gross public spend per premises passed is lower overall at £945 (rather than £2,636). Factoring in the likelihood that some of those premises passed to date would otherwise have received coverage through commercial deployments, the table below also includes the estimated number of additional covered premises. The gross public sector cost (i.e. before clawback) per additional covered premises over three years was £1,418. After allowing for clawback, this will fall to £1,225 to £1,276 per premises passed (depending on whether take-up stabilises at 60 or 80 percent in the long-term).

Table 4.12: Expected gross cost per premises and additional premises passed

Contract phase	Expected public sector cost (£m)	Premises passed by March 2021/22	Additional covered premises to date	Expected Gross public subsidy per gross covered premises (£)	Expected Gross public subsidy per additional covered premises (£)
Phase 3 to date (before clawback)	273.3	289,063	192,700	945	1,418
Phase 3 to date (before clawback)	236.0 to 245.8	289,063	192,700	816 to 850	1,225 to 1,276

Source: Ipsos UK analysis; Superfast Status Report, November 2022

4.10 Overview of findings

4.10.1 Overview of results

The table below provides a summary of the estimated impact of the Programme on areas benefitting from subsidised coverage under Phase 3 of the Programme by September 2021 (note that these do not include the results of the panel models as these provide a direct estimate of additionality as discussed below). The models provided a consistent view on the effects of the programme:

- **Impact on broadband coverage:** Subsidised coverage through Phase 3 of the Programme led to significant positive impact on the availability of superfast and gigabit capable broadband services by the end of September 2021. Subsidised coverage increased the share of premises in the programme area able to access superfast speeds by 44 to 48 percentage points, and the share of premises with gigabit capable coverage by 43 to 59 percentage points. The impact of the programme on NGA availability was relatively small, however, indicating that in its absence, most premises would have benefitted from some form of enhanced connectivity (albeit via technologies less able to deliver download speeds of 30Mbit/s or higher). These findings are consistent with prior research into the impacts of the programme on broadband coverage.

- **Impact on take-up:** Subsidised coverage led to a significant increase in the maximum download speeds of connections taken by households and/or businesses by September 2021 (34 to 62 Mbit/s).

However, the impacts of the programme on average download speeds were relatively small. This indicates that 'early adopters' have taken advantage of the enhanced broadband connectivity enabled by the Programme. However, the Programme had not led to widespread take-up of faster broadband services by September 2021. It should be noted that most subsidised coverage was delivered in 2019 and 2020. As take-up will lag deployment, it is premature to draw any firm conclusions on the impact of the programme on take-up of faster internet services. Again, this is consistent with prior research into the impacts of the programme on take-up.

Table 4.13: Estimated impact of Phase 3 on areas benefitting from subsidised coverage by September 2021

Outcome	Difference-in-Differences	Propensity Score Matching with Difference in Differences	Control group regression
NGA availability (% of premises)	3.2 to 7.5	4.4	3.5
Superfast availability (% of premises)	45.8 to 46.6	43.5	40.9
Gigabit capable availability (% of premises)	52.2 to 56.2	50.2	43.2
Average download speeds of connections (Mbps)	-	-	0.6
Maximum download speeds of connections (Mbps)	34.7 to 59.2	52.6	33.7
Average upload speeds of connections (Mbps)	5.8 to 6.3	4.4	0.9
Number of connections with download speed of 30Mbps+	0.8 to 1.2	3.9	-1.0

Source: Ipsos analysis. '-' denotes that the result was not statistically significant.

4.10.2 Additionality of subsidised broadband infrastructure

Estimates of the overall number of additional premises benefitting from NGA, superfast and FTTP/Gigabit capable availability by September 2021 have been derived by multiplying the estimated impact of the programme on the share of premises with enhanced broadband by the number of premises on the postcode:

- **NGA coverage:** The programme is estimated to have led to 50,000 to 117,000 additional premises with NGA coverage (with a larger estimate of 117,000 premises derived from panel models considered implausibly large given the observed trends in NGA coverage). Additionality (i.e. the share of premises benefitting from superfast coverage that would not have in the absence of the programme) is estimated at between 7 and 17 percent, with the most estimates towards the lower end of this range. This implies that to a large degree, premises benefitting from the Superfast Broadband Programme would have received some form of NGA coverage in its absence.

- **Superfast availability:** The Programme is estimated to have increased the number of premises that can access superfast broadband services (30Mbit/s or above) by 202,000 to 313,000 by the end of

September 2021. The associated rate of additionality ranges from 69 percent to 107 percent. This indicated that while many premises may have received NGA coverage in the absence of the Programme, these premises would not have been able to access at least superfast speeds (indicating the Programme has been highly effective in delivering against its primary objective).

- **FTTP/Gigabit capable coverage:** Subsidised coverage is estimated to have led to 193,000 to 378,000 additional premises with FTTP/Gigabit capable coverage. The rate of additionality ranges from 66 percent to 129 percent (with most estimates just above 100 percent). This indicates that the Programme has also been highly effective in bringing gigabit capable technologies to rural areas.

Table 4.14: Estimated additionality of NGA, Superfast and Gigabit capable coverage across methods

	Impact on outcome	Number of premises on postcodes	Number of premises upgraded	Premises enabled attributable to programme	Implied additionality
NGA availability					
Simple DiD	7.5	531,105	292,618	39,833	14%
DiD regression with controls	5.2	531,105	292,618	27,617	9%
Matched sample regression	4.4	531,105	292,618	23,369	8%
Control group regression	3.2	531,105	292,618	16,995	6%
Panel models	-	531,105	292,618	117,047	40%
Superfast availability					
Simple DiD	46.6	531,105	292,618	247,495	85%
DiD regression with controls	45.8	531,105	292,618	243,246	83%
Matched sample regression	43.5	531,105	292,618	231,031	79%
Control group regression	40.9	531,105	292,618	217,222	74%
Panel models	-	531,105	292,618	201,906	69%
FTTP/Gigabit capable availability					
Simple DiD	56.2	531,105	292,618	298,481	102%
DiD regression with controls	52.2	531,105	292,618	277,237	95%
Matched sample regression	50.2	531,105	292,618	266,615	91%
Control group regression	43.2	531,105	292,618	229,437	78%
Panel models	-	531,105	292,618	193,128	66%

Source: Ipsos analysis

4.10.3 Impacts on the Programme area

The analyses were also extended to explore the impacts of the Programme on all postcodes included in the build plans of Phase 3 schemes (i.e. including those areas that had not yet benefitted from subsidised coverage) to explore any unintended outcomes of the Programme across the target area as whole. These findings are summarised in the following table.

Previous results of this analysis suggested that the Programme had a negative effect on enhanced broadband availability across the overall Programme area (suggesting it had delayed coverage in some area). Such effects are no longer visible now the analysis has been extended to 2021, indicating that any negative effects via the delay of deployment were only temporary. While the estimated effects of the Programme across the programme area are smaller than for areas that received subsidised coverage, this would be expected given the inclusion of areas that had not yet received subsidised coverage.

Table 4.15: Estimated impact of Phase 3 on all postcodes in the build plans of Phase 3 schemes by September 2021

Outcome	Difference-in-Differences	Propensity Score Matching with Difference in Differences	Control group regression
NGA availability (% of premises)	2.2 to 3.2	2.0	1.7
Superfast availability (% of premises)	29.9 to 30.6	28.3	32.8
Gigabit capable availability (% of premises)/	28.9 to 30.5	28.4	44.4
Average download speeds of connections (Mbps)	-3.8 to -7	-2.4	No effect
Maximum download speeds of connections (Mbps)	11.4 to 12.9	10.0	38.9
Average upload speeds of connections (Mbps)	2.5 to 3.1	3.0	2
Number of connections with download speed of 30Mbps+	-0.4	No effect	-0.6

Source: Ipsos analysis. '-' denotes that the result was not statistically significant.

For more information

3 Thomas More Square
London
E1W 1YW

t: +44 (0)20 3059 5000

www.ipsos-mori.com
http://twitter.com/IpsosMORI

About Ipsos Public Affairs

Ipsos Public Affairs works closely with national governments, local public services and the not-for-profit sector. Its c.200 research staff focus on public service and policy issues. Each has expertise in a particular part of the public sector, ensuring we have a detailed understanding of specific sectors and policy challenges. Combined with our methods and communications expertise, this helps ensure that our research makes a difference for decision makers and communities.