Ipsos MORI
Social Research Institute

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Superfast Broadband Programme Evaluation

Annex A: Reducing the Digital Divide

Technical Report

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1 Reducing the Digital Divide

This technical report presents the results of a series of analyses exploring the impact of the Superfast Broadband programme on superfast broadband availability and download speeds. The paper also provides an assessment of the cost-effectiveness of the programme.

1.1 Background to the Programme

The Superfast Broadband programme was introduced in 2010/11 in response to concerns that the commercial deployment of superfast broadband[1] would fail to reach many part of the UK due to the cost of installing the technology relative to expected revenues. On the expectation that extending superfast broadband coverage to these areas would produce economic, social and environmental benefits that cannot 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.

Broadband Delivery UK (BDUK) - a Directorate of the DCMS - is the accountable body with responsibility for delivery. However, with the acknowledgement that delivery of the programme would need to address locally specific issues that could not be adequately managed from central Government, the programme was delivered in partnership with local authorities and the Devolved Administrations. Local Authorities and Devolved Administrations were challenged to match central Government funds on a 1:1 basis, and were responsible for the procurement and management of contracts with suppliers to deliver the infrastructure. By September 2017, £685m of BDUK funds and £903m of matched funding had been committed to 89 local projects across Phase One and Two of the programme. These contracts are expected to extend superfast coverage to 5.3m premises (of which 4.8m had been delivered by the end of December 2017[2]).

1.2 Analytical Framework

The direct effects of the programme were primarily expected take the form of the additional premises covered by superfast broadband infrastructure subsidised by BDUK and local authorities and associated increases in available download speeds. The extent of these effects will be determined by the following factors:

- Additionality: Making subsidies available for infrastructure delivery involves a risk that private sector 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 extent to which increases in superfast broadband availability can be attributed to the Superfast Broadband programme will depend on the effectiveness of mechanisms to ensure public resources are allocated to schemes that would not have been deemed by suppliers to be commercially viable without a subsidy. These mechanisms included:

[1] Defined as a download speed of 24 Megabits per Second (Mbit/s or 1m bits of data per second).

[2] Broadband Performance Indicator, December 2017. Available at https://www.gov.uk/government/collections/broadband-performance-indicators (accessed May 2018).

- Allocation of subsidies: Subsidies were allocated to Local Authorities based on BDUK's initial assessment of the gap funding[3] requirement to upgrade each cabinet in the UK. In Phase One, 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 Two, resources were allocated based on the gap funding needed to reach the 95 percent coverage at the lowest cost[4]. There was an aspiration that local authorities would match BDUK resources with local funds on a 1:1 basis, using their own funds or other resources available to support local economic development. Several local authorities were deemed ineligible for BDUK support because existing commercial plans were already extensive.

- Open Market Review and public consultation: Local authorities were required to manage an Open Market Review and public consultation process before they issued tenders under Phase One and Two of the scheme. The first stage of this process involved requesting suppliers to describe their commercial plans to roll-out basic and superfast broadband coverage over a defined time frame. This process classified postcodes into three groups:

  - White postcodes where there were no commercial plans to roll-out superfast broadband
  - Grey postcodes where one provider was offering or expected to offer superfast broadband services, and,
  - Black postcodes where multiple providers were offering or expected to offer superfast broadband

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

- Tendering: This view on the near term roll out of broadband at the local level was expressed in a 'Speed and Coverage Template' (SCT), and was used in tendering exercises in which local authorities sought to procure additional investment in local telecommunications infrastructure. Local authorities had the option to procure through a framework contract established by BDUK or through using an OJEU process. Only white postcodes were eligible for subsidised infrastructure, with competing suppliers outlining which postcodes they proposed to cover for the available funding. Suppliers were required to provide a project finance model, which included estimates of the overall costs associated with delivering the project, take-up assumptions, and expectations of future revenues, which determined the overall level of gap funding subsidy to be offered.

- 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 principle underlying contracts 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 contract coverage to a greater number of premises than originally offered. Any unused public funding would also remain available for further investment.

- Gain-share: Further protections for the public sector were introduced through 'gain-share' clauses in contracts. If take-up proved to be higher than anticipated at the tendering stage then suppliers were required to return a share

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

[4] 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.

of the excess revenues to the Investment Fund based on the investment ratio (and again, these funds could be recycled to support further coverage).

- Supplier behaviour during the Open Market Review process: It could be anticipated that some suppliers would see an incentive to understate their commercial plans during the Open Market Review process to increase the likelihood they secure subsidies. Discussions with BDUK suggested, however, that there may be disincentives for this type of behaviour if an understatement of commercial plans encouraged the emergence of a subsidised competitor. There was also a possibility that some suppliers used the Open Market Review process to overstate their commercial plans to preserve local market dominance. As the Open Market Review process signalled future availability of superfast broadband to businesses and households, effects of this type could have negative consequences if they discourage investment in area in which superfast broadband services did not eventually come forward.

- Supplier behaviour during the tendering process: The underspend and gainshare mechanisms of the contract aimed to reduce systematic incentives for suppliers to overstate the gap funding requirement. Overstatement of costs at the tendering stage would be recovered via the underspend clawback mechanism[5], while a share of any understatement of future revenues would be recovered via the gain-share mechanism. Understating expected costs or overstating take-up expectations could result in the supplier ultimately taking a loss. In both cases, this would reduce the level of subsidy that could be claimed – potentially to a level that was smaller than the amount needed to make the project commercially viable.

- Crowding out: The provision of subsidies for superfast broadband investment has the potential for negative impacts on other areas if suppliers face 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 programme, which began as the main suppliers were completing the bulk of their commercial roll-out.

- Crowding in: As suggested above, take-up of subsidised superfast broadband availability has been higher than expected, and it is equally possible that the scheme helped demonstrate the commercial viability of infrastructure investment in the areas targeted. This could potentially encourage suppliers to upgrade cabinets 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, the announcement in 2014 that the Government was providing further public subsidy could have influenced supplier expectations, causing them to hold back investment in anticipation that further subsidies will become available. Experiences with commercially funded deployments may also have demonstrated commercial viability. In this case, crowding-in effects could not be wholly attributed to the programme.

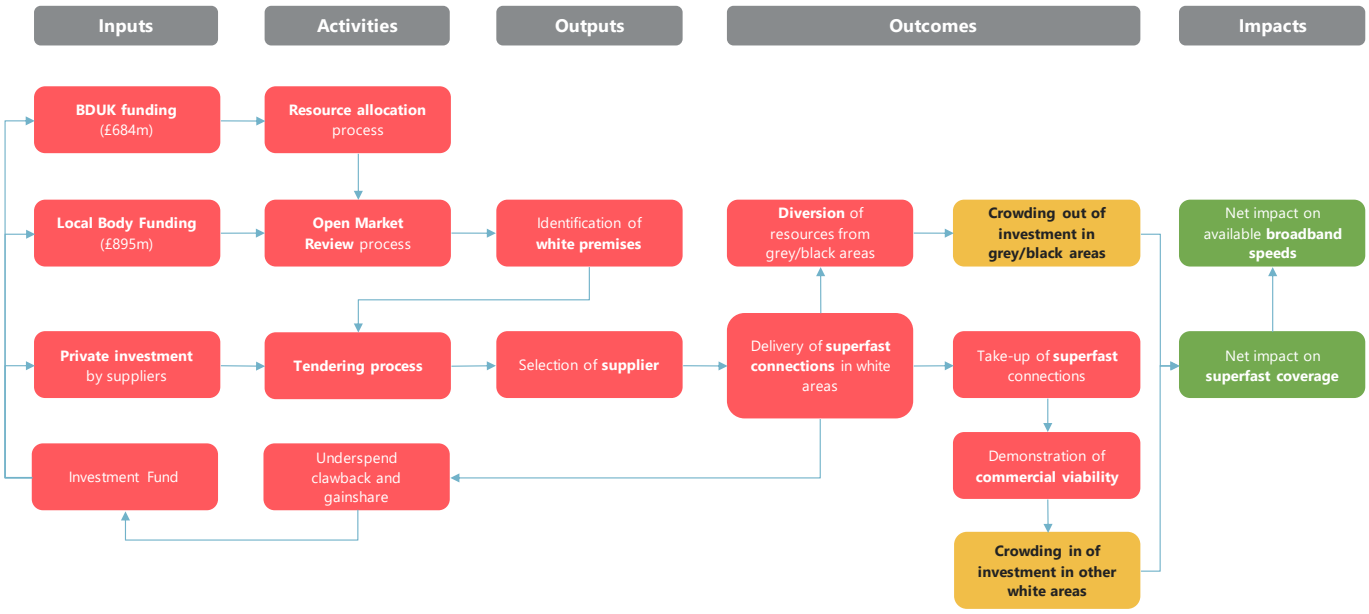
- Variability of impacts: The effects of the programme could be expected to vary across areas with different characteristics. If the supplier installation decision is determined by the degree to which the expected profits exceed the expected costs, then local variability in the effects of the programme would be driven largely by factors determining the cost of installation and maintenance (such as local topography, characteristics of the local network, or distance from regional population centres) and demand for the technology, e.g. incomes of households, the industrial structure of the local economy, or the speed of existing broadband services. There was evidence that some suppliers applied invariant assumptions with respect to take-up, and in this case, cost drivers were likely to be more significant in driving variability. The drivers of

[5] Unless subsidies encourage less efficient delivery.

variability are also unlikely to be static over time - technological progress may result in reductions in the cost of installation, while demand for superfast speeds may rise as more data intensive applications emerge.

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. Evaluation questions relating to the effectiveness of the resource allocation process will be addressed as part of the wider evaluation plan for the Superfast Broadband programme and are out of the scope of this study.

Figure 1.1: Logic Model – Infrastructure Effects of the Superfast Broadband Programme



1.3 Data

The data driving the analysis set out in this paper was derived from a variety of sources. This section provides an overview of the data available, issues relating to comprehensiveness or quality, and implications for the findings.

1.3.1 Connected Nations Report

Ofcom's Connection Nations report provided the evidence on the key outcomes of interest for the analysis including broadband availability, available speeds and average download speeds (which gives an indication of take-up of available speeds) at a postcode level between 2012 and 2016. The data provides a snapshot of local connectivity in June of each year and gives one year of data before subsidised deployments started to be delivered. The number of postcodes included in the report has changed from year-to-year[6], and in compiling the data any postcode with missing data for one or more years was dropped from the analysis. This gave a sample of 1.55m postcodes which excluded any new postcodes that may have emerged because of new housing or commercial developments on greenfield sites.

The following analyses should be reviewed bearing in mind the following limitations of the data:

[6] Conversations with Ofcom indicated this variability was driven by refinements to the set of postcodes included in the Connected Nations report as postcodes that would not be expected to have broadband connectivity (e.g. postcodes for statues) were covered in earlier years.

- **Measures of superfast availability:** The Connected Nations data has increased in resolution over time with a greater number of variables included in the dataset in each year. In 2012 and 2013, the dataset only gives a binary measure of whether a postcode has Next Generation Access (NGA)[7] access or not[8], though from 2014 onwards the data describes the percentage of premises with NGA and superfast access. It was only possible to construct a consistent measure of superfast availability by converting post 2014 measures of NGA access into a binary measure – achieved by assuming a postcode had NGA access if more than 50 percent of the premises on the postcode had NGA access. This measure more closely tracked aggregate changes[9] in NGA access than the available alternatives[10] — but is likely to overstate NGA coverage in earlier years, potentially leading to an understatement of the impact of the programme. It should be noted that while NGA access is positively correlated with the availability of superfast broadband, with a Pearson's correlation coefficient of 0.7[11], it is not a strong predictor in some cases, for example where the distance of premises from the serving cabinet is large. As such, a focus on NGA access will overstate superfast availability.

- **Definition of superfast:** The programme's effects on superfast availability is explored in some of the analyses set out below using data from 2014 to 2016. However, there are differences in the definition of superfast employed by the programme (>24Mbit/s) and in the Connected Nations data (>30Mbit/s). In these cases, analyses will understate the effect of the programme on superfast availability where subsidised coverage has delivered speeds of between 24 and 30 Mbit/s.

- **Missing data:** The Connected Nations data describes average and maximum download speeds. Average and maximum download speeds are missing for a meaningful share of postcodes in early years due to insufficient numbers of premises or missing data. Restricting the sample to postcodes where speed data is available in all years between 2012 and 2016 reduces the sample size to 1.2m postcodes, though data on NGA access is available for all postcodes. Clearly, there are questions as to how far there are systematic differences between those postcodes for which speed data is and is not available, and the analyses set out below have sought to explore the effect of including and excluding these postcodes on the estimated impact of the programme.

- **Truncated data:** Finally, observations of low and high download speeds are truncated in the 2012 and 2013 Connected Nations data. Speeds of less than 4Mbit/s are recorded as '<4Mbit/s' and speeds greater than 30MBits/s are recorded as '30Mbit/s' – and as such cannot be included as a control variable without further reducing the size of the available sample.

- **Suppliers covered:** Connected Nations is based on information provided by a sample of suppliers, and does not provide complete coverage of smaller telecoms suppliers. Where local schemes have been delivered by suppliers that do not provide information for Connected Nations, the effects of those schemes will not be visible in the data. Discussions with BDUK suggested that this applies to two Phase Two schemes delivered in Swindon and Windsor and Maidenhead, and checks have been made on possible distortionary effects by excluding these areas in some analyses.

[7] Defined by OfCom as: New or upgraded access networks that will allow substantial improvements in broadband speeds and quality of service. Can be based on a number of technologies including cable, fixed wireless and mobile. Most often used to refer to networks using fibre optic technology.

[8] The 2012 and 2013 OfCom datasets will have systematically overstated NGA coverage for the analytical purposes of this paper, as a postcode qualified as being passed by NGA if just one premise was enabled with NGA.

[9] I.e. the share of premises with NGA coverage, which is measured directly in the Connected Nations dataset between 2014 and 2016.

[10] Such as assuming a postcode has NGA coverage if at least one premises was covered by NGA.

[11] This was calculated based on the relationship between share of premises with NGA coverage and the share of premises with superfast (30 Mbit/s) coverage at a postcode level, as captured in the 2016 Connected Nations dataset.

1.3.2 Speed and Coverage Templates

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 MORI with all available SCTs, which covered almost all local schemes that had been contracted under Phase One and Two by August 2017. Postcode level data in the SCTs was aggregated and matched to the Connected Nations datasets, any postcodes that did not match were dropped from the analysis. Table 1.1 provides a breakdown of the postcodes available by their status as defined in the SCTs. In summary:

- White postcodes: There were 370,073 white postcodes eligible for BDUK subsidies (24 percent of postcodes in the UK) under Phase One of the programme and 165,477 postcodes eligible for BDUK subsidies under Phase Two of the programme (11 percent of postcodes in the UK).

- Postcodes included in build plans: The build plans associated with local schemes covered 277,394 postcodes (18 percent of postcodes in the UK) in Phase One and a further 87,326 postcodes in Phase Two (6 percent of postcodes in the UK). These figures exclude any postcodes that were included in build plans for non-superfast delivery.

- Grey or Black Postcodes: A total of 584,160 postcodes were deemed as 'grey' or 'black' in the SCT template, and therefore ineligible for BDUK subsidies (around 38 percent of postcodes in the UK). The number of ineligible postcodes rose to 728,935 in Phase Two (47 percent of the UK).

- Descoped and ineligible LAs: A further 229-300,000 postcodes were ineligible for BDUK subsidies because they were 'de-scoped' by the Local Authority or Devolved Administration or were located in Local Authorities deemed outside the scope of the programme by BDUK because commercial deployments were expected to be extensive (or Local Authorities voluntarily declared themselves ineligible). The ineligible local authorities were Birmingham, Bristol, Kingston-Upon-Hull, Manchester and Salford – and the 33 Boroughs of London - while Coventry, Portsmouth and Southampton did not take part. This was equivalent to just under 15 percent of the postcodes in the UK.

- Postcodes not present in SCT or areas without schemes: The SCTs prepared by local bodies did not always provide full coverage of the postcodes within their area. Additionally, some local bodies eligible for BDUK subsidies did not come forward with a scheme (e.g. Luton). It is unknown if these postcodes were 'white,' 'grey' or 'black'. This accounted for 14 percent of postcodes in the UK under Phase One, and 17 percent under Phase Two.

- Area excluded from the analysis: SCT templates were not available for a small number of local areas (Gloucestershire & Herefordshire and North Yorkshire) who contracted their programmes via an OJEU process rather than using the BDUK Framework Agreement. Additionally, there was no SCT template available for Wales. No information is available on the postcodes included within the build plan of these schemes or those that were eligible and these areas have been dropped from most analyses provided in this report. Additionally, a prior evaluation scoping study prepared for BDUK recommended the exclusion of Cornwall owing to the contaminating effect of the broadband coverage subsidised through the EU Convergence programme. On this basis, Cornwall has also been excluded in the following analyses[12].

[12] It is understood that a similar issue applies in Northern Ireland with EU funded programmes bringing superfast coverage to towns and villages. However, prior programmes were planned - and to a large extent delivered - before the Superfast Broadband programme. Their effects on coverage would have been captured through the Open Market Review process, enabling these external factors to be controlled for in the analysis.

Areas excluded from the analysis for the above reasons represented 9.5 percent of postcodes in the UK. It should be noted that the exclusion of these areas may mean that the results are not fully representative of the impacts of the programme. It is understood that Wales used a different process for allocating BDUK subsidies which may have produced different effects. North Yorkshire and Gloucestershire and Herefordshire were also amongst the first to contract suppliers, which could also influence estimates of the impact of the programme. For example, the results suggest that subsidies were more effective in accelerating superfast coverage in earlier years of the programme, and the exclusion of these areas may lead to an understatement of its overall effect, though the risks of crowding out would likely be more acute.

Table 1.1: Overview of Speed and Coverage Templates, Phase One and Phase Two

Status	Phase One		Phase Two	
	Number	Percentage	Number	Percentage
White postcode within build plan defined in SCT	277,394	17.9	87,326	5.6
White postcode out of build plan defined in SCT	92,679	6.0	78,151	5.0
Grey or Black postcode in SCT	584,160	37.7	728,935	47.1
De-scoped postcode or 'ineligible' LA	229,333	14.8	229,630	14.8
Postcodes not present in SCT or in areas with no scheme	218,234	14.1	277,758	17.9
Area excluded from analysis	147,395	9.5	147,395	9.5
Total	1,549,195	100	1,549,195	100.0

Source: SCT templates, Ipsos MORI analysis

1.3.3 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 end of quarter one 2017/18 were used to support the analyses reported below and elsewhere in this evaluation. These provided details of some 5.2m premises that were claimed to have been upgraded by providers. Not all of these premises would have received coverage subsidised by BDUK, and a number of steps were taken to refine this dataset:

- Predicted speeds: Around 580,000 premises (in 96,700 postcodes) were claimed to have been upgraded to an available download speed of less than 24Mbit/s. This might occur, for example, if the premise was too far from the serving exchange or cabinet, and includes delivery of basic broadband funded by BDUK which is treated as out of scope of the evaluation. While these premises claimed were excluded for the purposes of assessing the impact of the programme on such superfast availability, they have been included in other analyses examining the downstream effects of the premises upgraded).

- Dates: A further 3,600 premises upgraded were dropped from the dataset because the reported date of the upgrade occurred before the programme began. It is assumed that these represent data entry errors, and account for a negligible share of the overall number of premises upgraded.

- Matching to Connected Nations: Finally, 50,000 premises upgraded were associated with postcodes that were not present in the Connected Nations dataset. These were also excluded from the analysis as there were no observations of the outcomes of interest.

The table overleaf maps the resultant sample of upgraded premises to the status of areas described in Table 1.1. Seventy one percent of claimed delivery under Phase One and 92 percent under Phase Two occurred in postcodes included in the build plans of local schemes defined in the SCT. A large share of this apparent discrepancy is accounted for by delivery recorded in those areas that have been excluded from the analysis (20 percent under Phase One and five percent under Phase Two). However, the data also points to some claimed delivery outside of the planned deployment defined in the SCT:

- Delivery in other white postcodes: Just over 200,000 premises upgraded were claimed on white postcodes outside of the build plan defined in the SCT. Discussions with BDUK suggested that this would occur primarily where the engineers reached a cabinet and found that they could not upgrade, e.g. for technical reasons or if there was a planning constraint. In this case, the engineers may move on to the next eligible postcode. In principle, these changes should have been captured in the SCT via a change request, though in practice the SCTs do not provide a perfect record. These postcodes were reallocated to the set of postcodes benefitting from BDUK subsidies. This increased the number postcodes included within the build plans of Phase One schemes from 277,394 to 292,742 postcodes and the number of postcodes included within the build plans of Phase Two schemes from 87,326 to 87,861.

- Delivery in ineligible areas: Almost 5 percent of premises claimed under Phase One and a smaller share of premises under Phase Two were located in ineligible areas, i.e. the grey, black, and de-scoped postcodes, and postcodes in ineligible local authorities. Discussions with BDUK suggested that this would primarily occur because the serving cabinets upgraded would simultaneously serve premises on white and ineligible postcodes, and providers would report the full set of premises upgraded. In the analysis, these postcodes were not reallocated to the set of postcodes considered to have benefitted from BDUK investment as suppliers did not receive a subsidy to upgrades these premises.

Table 1.2: Claimed Number of Premises Upgraded, 2013 to 2017

Status	Phase One		Phase Two	
	Number of Premises Claimed	Percentage	Number of Premises Claimed	Percentage
White postcode within build plan defined in SCT	3,051,058	70.6	287,780	91.7
White postcode out of build plan defined in SCT	196,978	4.6	4,765	1.5
Grey or Black postcode in SCT	188,149	4.4	4,813	1.5
De-scoped postcode or 'ineligible' LA	5,815	0.1	173	0.1
Postcodes not present in SCT or in areas with no scheme	6,532	0.2	170	0.1
Area excluded from analysis	873,068	20.2	16,217	5.2
Total	4,321,600	100.0	313,918	100.0

Source: C3 Reports, Ipsos MORI analysis.

1.3.4 Other data supplied by BDUK

BDUK also supplied a range of other data describing the pre-programme characteristics of postcodes in the UK. These 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. These variables included:

- Modelled[13] length of the line from the Serving Exchange to the Serving Cabinet to the Premise;
- Modelled length of the line from the serving cabinet to the premise;
- Modelled share of exchange only Lines;
- Modelled number of delivery points at the serving exchange;
- Modelled number of delivery points at the serving cabinet (equalling zero for postcodes served by Exchange Only lines);
- Whether the postcode was within the Virgin Media or K-COM footprint in 2013;
- Number of residential and non-residential delivery points on the postcode in 2013.

A share of postcodes were served by more than one cabinet. In these cases, the variables above were calculated as a weighted average across the cabinets serving the postcodes, with the share of delivery points served by each cabinet providing the weights. The available data did not capture all factors likely to influence installation costs, such as topography or local planning constraints.

1.3.5 Other control variables

Finally, a further set of control variables were collected describing the characteristics of the resident population before the programme was delivered. These included measures of the size of the working age population and population aged 65 plus at the output area level derived from the 2011 Census[14] which were also used to calculate measures of population and premises density. An indicator of whether a postcode was located within rural or urban areas was derived from the ONS Postcode Lookup table. Finally, measures of the economic performance of areas in 2013 were derived from the Annual Survey Hours and Earnings and the Annual Population Survey respectively, including gross weekly earnings, and unemployment and employment rates. The latter were observed at the level of the local authority district.

[13] Modelled by BDUK analysts.

[14] An output area is the smallest unit against which Census statistics are reported, representing around 11 to 12 postcodes.

2 Programme Overview

This section provides an overview of the delivery of the Superfast Programme between 2012 and 2016.

2.1 Characteristics of Postcodes Benefitting from the Superfast Broadband Programme

The table below provides an overview of the characteristics of postcodes included in the build plans of the local schemes funded through the Superfast Broadband Programme. The table below does not cover the 147,000 postcodes that have been excluded from the analysis (see section 1.3.2).

Table 2.1: Characteristics of Postcodes Benefitting from Superfast, 2012-13

Characteristics	Phase One Build Plans	Phase Two Build Plans	Other White Postcodes	Ineligible / Other Postcodes
Broadband Availability in 2012				
% of postcodes with Next Generation Access	9.0%	18.5%	38.7%	71.2%
Average Maximum Download Speed (Mbit/s)	10.9	9.6	9.4	13.1
Average Download Speeds (Mbit/s)	7.8	7.2	8.4	13.7
Network Characteristics in 2013				
Length of Line from Exchange to Premises (m)	2,742	3,193	3,655	2,221
Share of Premises with Exchange Only Lines (%)	20.8%	17.0%	23.2%	5.1%
Delivery Points at Serving Exchange	5,782	8,090	9,383	17,204
Delivery Points at Serving Cabinet	239	216	234	375
% of postcodes in Virgin Media footprint	3.5%	6.2%	7.2%	46.3%
Number of Residential Delivery Points	13.5	12.5	10.9	19.3
Number of Non-Residential Delivery Points	1.0	1.4	1.0	0.7
Estimated cost to upgrade serving cabinet to superfast (£)	66,984	63,876	63,821	62,031
Estimate upgrade cost per premises upgraded (£)	313	401	403	184
Area Characteristics in 2013				
% of postcodes in rural areas	74%	67%	63%	16%
Working age population (in Output Area)	178	210	202	200
Population aged 65+ (in Output Area)	57	60	54	51
Population Density in OA (Population per Square Km)	1,421	1,065	1,200	4,629
Premises Density in OA (Premises per Square Km)	939	689	764	2,509
Gross weekly earnings in LA (£)	509	514	522	517
Employment rate in LA (%)	73.7	73.0	72.7	70.7
Unemployment rate in LA (%)	6.7	7.4	7.1	8.2

The table suggests – as expected - that those postcodes included in the build plans of local schemes differ in systematic ways from postcodes that were not:

- Broadband availability: Postcodes benefitting from BDUK subsidies had low penetration of NGA access in 2012 relative to postcodes that were ineligible (9 percent and 19 percent for postcodes included in Phase One and Phase Two schemes respectively). This was also reflected in maximum and average download speeds, though these figures should be treated with caution owing to the problems caused by the truncation of observations speeds described in the preceding section, i.e. postcodes with speeds of less than 4Mbit/s or more than 30Mbit/s are excluded from these averages, likely making groups of areas appear more similar than they may have been in practice.

- Investment costs: Postcodes benefitting from the programme also shared a range of characteristics that would have increased the investment cost associated with upgrading premises to superfast broadband speeds. Firstly, the share of premises with exchange only lines was substantially higher on ineligible postcodes than on postcodes included within the build plans of schemes. Upgrading exchange only lines requires the installation of a new cabinet, increasing investment costs. The length of the line from the serving exchange to the premises (via the cabinet) was also substantially higher on postcodes included within local schemes. As available download speeds fall with distance from the exchange, this would have also increased the investment cost associated with enabling the relevant premises with superfast broadband speeds. This is reflected in BDUK's ex-ante estimate of the cost of upgrading the serving cabinet per premises upgraded. As noted above, information on other factors likely to influence investment costs was unavailable.

- Commercial attractiveness: The number of premises connected to the serving cabinet and exchange also tended to be lower on postcodes included within local schemes than on postcodes that were ineligible. This will increase the cost per premises upgraded, reflected again in BDUK's ex-ante estimates of the cost of upgrading premises on the postcode. The expected cost per premises upgraded was twice as high in postcodes included in Phase Two scheme than in ineligible postcodes.

- Area characteristics: The primary differentiating factor between postcodes included in the build plans of local schemes and those in ineligible areas was population density. Local schemes were primarily concentrated in rural areas with comparatively low population densities. The size of the resident population per square kilometre people was more than two thirds lower in postcodes benefitting from BDUK subsidies. This was also reflected in premises densities. Differences in economic performance were less apparent. However, as wages, unemployment and employment could only be observed at the local authority level, neighbourhood level variation that may be more significant will be masked.

- Other differences: Postcodes included in schemes funded through Phase Two appeared to be less commercially attractive than those funded through Phase One. White postcodes that were not included in either Phase One or Two also appeared to share more similar features to those included in the build plans of schemes funded than postcodes that were ineligible.

2.2 Delivery of the Programme

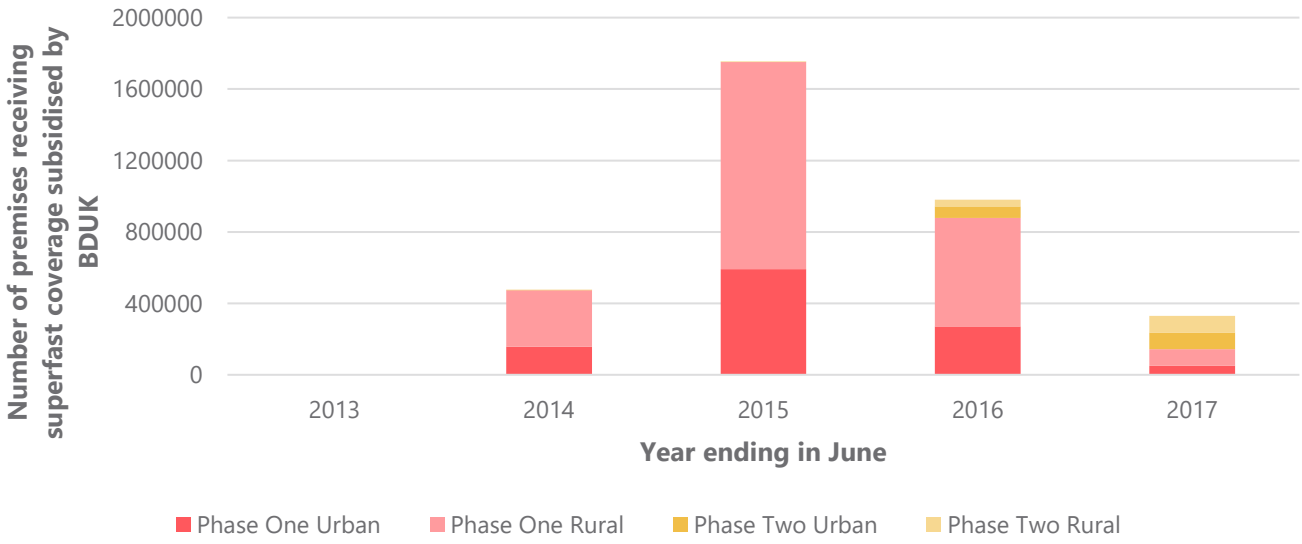
The following figure provides an overview of the time profile of the delivery of subsidised coverage over Phase One and Phase Two in urban and rural areas[15]. The analysis is restricted to delivery of coverage with predicted speeds of 24Mbit/s or

[15] Postcodes were classified using the data in the August 2017 ONS Postcode Directory based on the 2011 Census and the preferred definition of urban and rural postcodes given by BDUK (the urban and rural indicator agreed with Defra in the Digital Taskforce Group). Postcodes in Northern Ireland were unclassified in this data, and were reclassified using the classifications based on the 2001 Census that are also available in the ONS Postcode Directory.

higher on white postcodes, and excludes the 147,000 postcodes for which SCT templates were unavailable. As highlighted above, Phase One of the programme involved the delivery of superfast coverage to 3.3m premises in these areas by quarter one 2017. Upgrades were primarily provided to postcodes classified as 'rural' (67 percent), with volumes peaking in 2015. Phase Two has so far involved smaller volumes, with 292,545 premises upgraded by the end of the first quarter of 2017. There was a stronger focus on urban areas in Phase Two up to the first quarter of 2017 (55 percent of premises upgraded were delivered on postcodes classified as urban). However, as noted above, 67 percent of postcodes in the build plans of Phase Two schemes were classified as rural, suggesting suppliers have upgraded urban postcodes first. The number of premises receiving upgraded coverage equates to 70 percent of the total estimated number of premises on postcodes in the scope of the scheme.

Information is not recorded in the C3 reports as to whether the premises receiving superfast coverage are residential or non-residential. An estimate has been derived based on the share of residential and non-residential delivery points on a postcode based on data provided by BDUK. These estimates suggest that the programme has been focused primarily on residential properties (some 93 percent).

Figure 2.1: Number of Premises Receiving Superfast (24Mbit/s) Coverage subsidised by BDUK, Areas for which SCT Templates are Available, 2013 to 2017

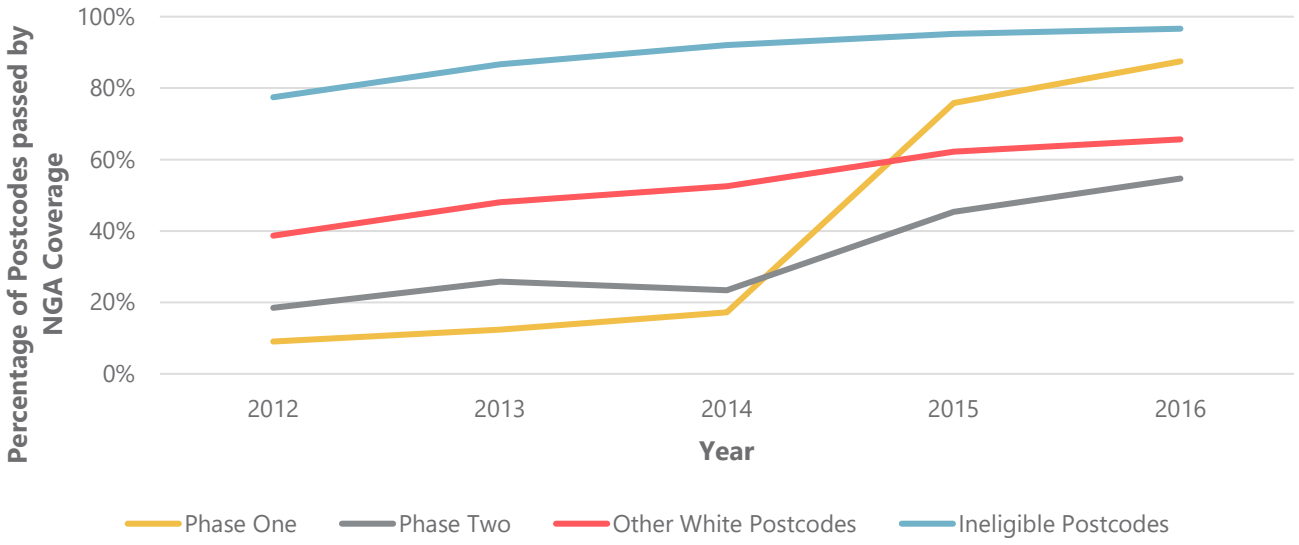


Source: C3 reports, Ipsos MORI analysis. Urban and Rural Areas classified using definition agreed with Defra in the Digital Taskforce Group

2.3 Changes in Connectivity

Changes in NGA availability on postcodes included within the scope of Phase One and Phase Two schemes are illustrated in figure 2.2. The share of postcodes with Next Generation Access within the build plans of Phase One schemes rose rapidly between 2012 and 2016 (from less than ten percent to 87 percent). There was a large increase in the share of postcodes with NGA access between 2014 and 2015, which coincided with peak delivery volumes. Postcodes included within the build plans of Phase Two schemes have also seen NGA coverage increase, though at a slower rate (from 18 percent to 55 percent). White postcodes that were not included within the scope of Phase One or Two schemes have also seen NGA coverage increase, while 95 percent of postcodes in ineligible areas had received NGA coverage by 2016.

Figure 2.2: Changes in Next Generation Access Coverage – 2012 to 2016

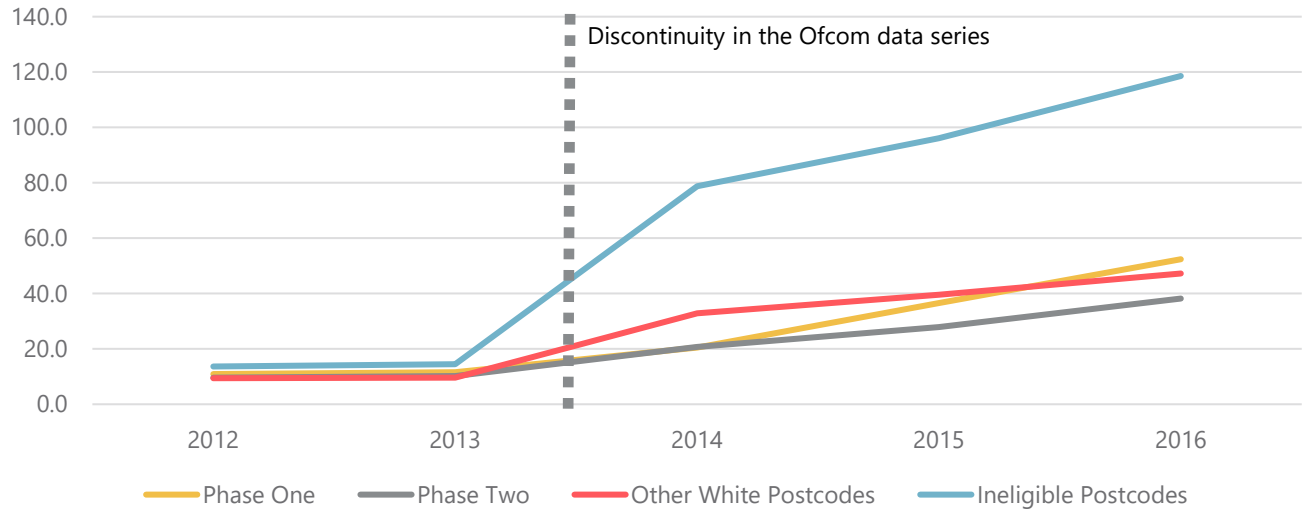


Source: Connected Nations, Ofcom, Ipsos MORI analysis

Figure note. A postcode is assumed to be covered by NGA if more that 50 percent of premises are passed by NGA from 2014 onwards (and if at least one premises is passed by NGA before 2014). This approach will be responsible for the apparent decline in NGA coverage between 2013 and 2014 in Phase Two areas.

The available data on maximum download speeds are subject to issues of comparability driven by the truncation of observed speeds in the 2012 and 2013 Connected Nations data. Average maximum download speeds on postcodes in and outside the areas covered by local schemes are displayed in Figure 2.3. Between 2014 and 2016, maximum speeds available on postcodes within the build plans of Phase One schemes rose from 20Mbits/s to 52Mbits/s. Speeds available on postcodes within the scope of Phase Two schemes rose more modestly (from 20Mbit/s to 38Mbit/s) over the same period. Available speeds continued to lag those available on white postcodes that were not included within the build plans of local schemes.

Figure 2.3: Maximum Available Download Speeds, 2012 to 2016

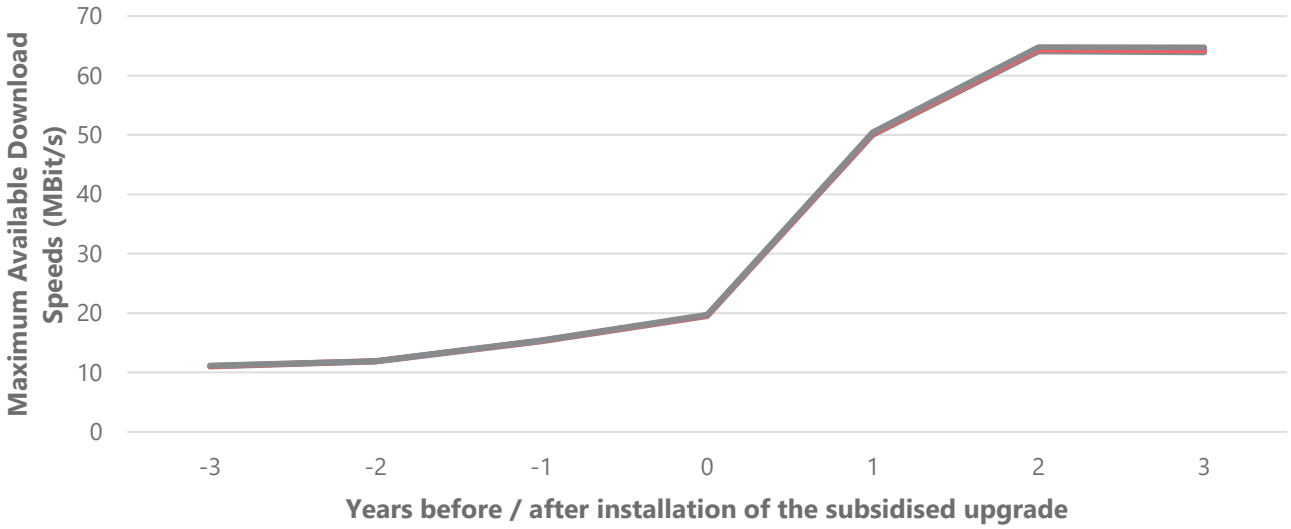


Source: Connected Nations and SCTs, Ipsos MORI analysis.

Figure Note. The large increase in speeds between 2013 and 2014 is attributable to a discontinuity in the available data, in which speeds above 30Mbit/s and those less than 4Mbits/sec were not reported exactly in the earlier Connected Nations reports.

To better illustrate the gross effect of the programme on maximum available speeds, the analysis was restricted to those postcodes benefitting from the programme for which data on available speeds was available in each year between 2012 and 2016. On average, in the areas covered by analysis, the maximum available download speeds increased from an average of just under 20Mbit/s in the year prior to the installation of the subsidised upgrade to an average of 64Mbit/s in the first two years following installation. Available speeds stabilised at this level in the years following the improvement.

Figure 2.4: Average Maximum Available Download Speeds on Postcodes Receiving Subsidised Coverage Before and After Installation of the Upgrade



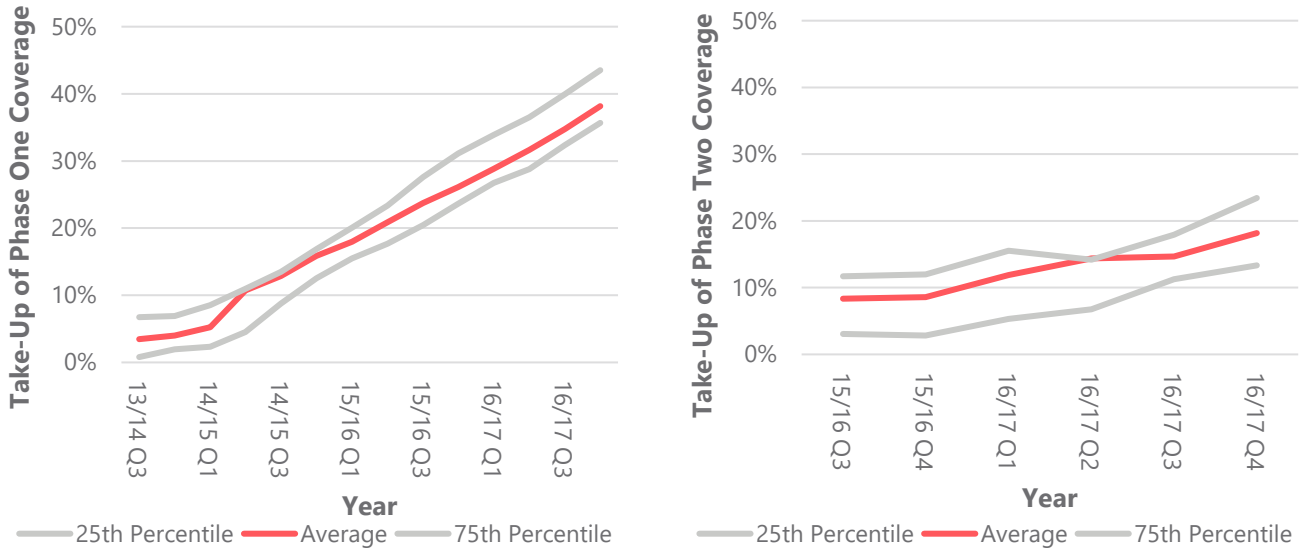
Source: Connected Nations and C3 Reports supplied by BDUK.

Figure Note. Data relates to 190,392 postcodes receiving subsidised coverage for which information on maximum download speeds was available between 2012 and 2016. 95 percent confidence interval displayed in grey.

2.4 Take-Up of Subsidised Coverage

The take-up up of subsidised superfast broadband coverage is monitored by BDUK. Figure 2.5 illustrates take up across Phase One and Phase Two from 2013/14 onwards. Take-up of coverage installed under Phase One of the programme grew steadily to an average of 38 percent at the end of 2016/17. Take-up of superfast broadband services enabled through Phase Two of the programme reached around 20 percent, slightly higher than achieved under Phase One over a similar period, presumably reflecting growth in demand for digital services. There was a degree of local variation in take-up rates, ranging from 29 percent to 54 percent under Phase One in 2016/17 and from 5 percent to 31 percent under Phase Two.

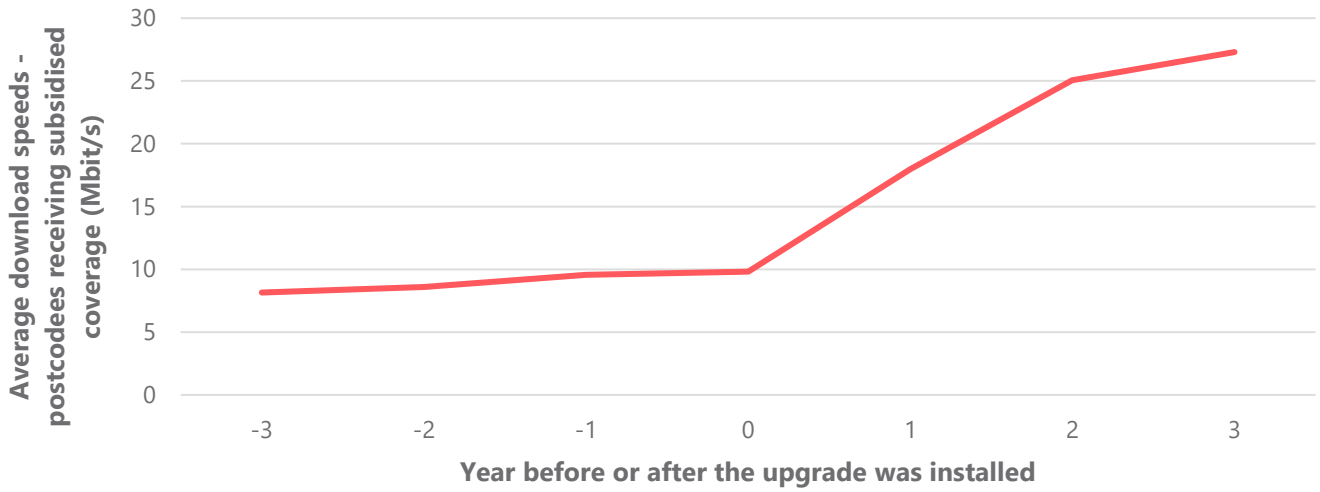
Figure 2.5: Take-Up of Subsidised Coverage Under Phase One and Phase Two



Source: BDUK Monitoring Information

Take-up of subsidised coverage has fed through into observable changes in average downloads speeds reported in the Connected Nations data. Figure 2.6 shows changes in average download speeds on postcodes benefitting from subsidised coverage before and after the connection was installed. As with the analyses set out in the preceding section, this analysis only includes postcodes for which information on average download speeds were available for each year between 2012 and 2016). Average download speeds rose from just under 10Mbit/s to just over 27Mbit/s in the three years following installation of the connection. This is a change in download speeds of 17Mbit/s which can be compared to the change in available speeds of 44Mbit/s to get an estimate of take-up of 39 percent, broadly comparable to the figures above.

Figure 2.6: Average Download Speeds on Postcodes Receiving Subsidised Coverage Before and After Installation of the Connection



Source: Connected Nations and C3 Reports supplied by BDUK.

Figure Note. Data relates to 190,392 postcodes receiving subsidised coverage for which information on maximum download speeds were available between 2012 and 2016.

2.5 Costs

A total of £1.6bn of public funding was originally committed to the local projects funded under Phase One and Phase Two of the Superfast Broadband Programme[16]. These contracts involved £689m of BDUK funding and £903m of public subsidies contributed by local bodies. Additionally, the contracts involved a commitment of £615m in supplier spending. The cost of the programme has varied against the expectations defined in these contracts for the following reasons:

- Underspend: The total cost of installation proved lower than expected by providers. The overall level of underspend on contracts is estimated at £127m. A total of £66m of this was reinvested in achieving higher coverage rates, for example, by extending Phase One contracts. The net reduction in the public contribution to investment costs was £60m.
- Take-up gainshare: Take up was higher than anticipated by providers and was expected to trigger payments to the public sector of £489m[17]. Again, a share of these resources (£84m) was reinvested in achieving higher coverage rates.

The total net cost of the programme following these adjustments is estimated at £1.1bn to deliver superfast broadband coverage to 5.3m premises at a unit cost of £211 (in nominal terms). The gainshare clauses in contracts helped deliver a substantial improvement in the unit cost per connection – the average cost per premises upgraded before payments received from gainshare is accounted for was £287[18], implying the mechanism delivered a reduction in unit costs of 36 percent.

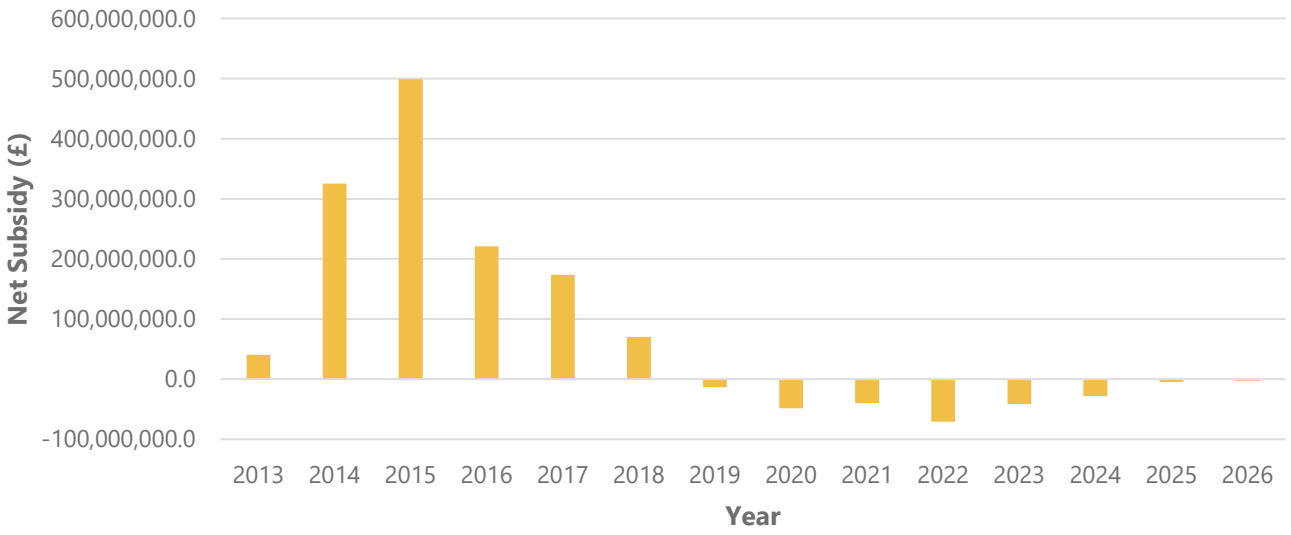
[16] The total contracted number of premises to be upgraded to superfast connectivity was 5.3m but this includes increases resulting from reinvestment of underspend and gainshare.

[17] Based on projections provided by BDUK in November 2017

[18] This figure removes the £404m expected in payments from gainshare, but includes the £84m reinvested in the programme.

BDUK also supplied forecasts of gainshare payments and underspend to 2030 to enable the costs of the programme to be presented in present value terms[19] and in real prices[20]. Overall, the present value of the net subsidy (in 2013) is estimated at £1.1bn (in 2016/17 prices), giving a unit cost per connection of £211. The time profile of expected costs and income are set out in Figure 2.7.

Figure 2.7: Forecast Delivery Costs and Income, 2013 to 2026 (present value in 2013, 2016/17 prices), expectations in September 2017



Source: BDUK monitoring information.

[19] With costs discounted using the rate of social time preference of 3.5 percent recommended in the Green Book and a base year of 2012.

[20] Accounting for inflation using the GDP deflators published by HM Treasury between 2012 and 2022, and assuming annual inflation of 1.7 percent per annum in line with the average of OBR forecasts between 2018 and 2022.

3 Impact Evaluation

This section sets out an assessment of the impact of the Superfast Broadband programme on the availability and use of superfast broadband services in targeted areas.

3.1 Issues Involved in Assessing Impact

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 claimed 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 use of these areas in a comparison group would understate the impact of the programme.

- Supplier choice: Suppliers were largely free to choose which white premises were targeted through the Phase One and Two contracts. It is not unreasonable to assume that suppliers selected the lowest net cost locations in each of these contracting rounds, and the use of white premises that did not receive BDUK investment as a counterfactual would produce problems in the opposite direction. Those premises in white areas that did not benefit from BDUK investment may have been the hardest to upgrade, and the least likely to have received superfast coverage in the absence of the programme.

- 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.

Given these complexities, several methods have been applied to explore the effects of the programme. These are set out below in order of least to most robust.

3.2 Matching Models

The first approach to assess impact explored in this paper was to select a comparison sample of postcodes that did not receive BDUK investment but shared similar observable characteristics to those that did before the programme began. This was achieved by applying a propensity score matching (PSM) approach in which statistical models[21] were developed to:

[21] This took the form of a Probit model: $\Pr(Y_i = 1|X_i) = \phi(X_i\beta)$. 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.

- Compare the characteristics of 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.

- Using these results, postcodes that were not included in the build plans of local schemes – but shared a similar predicted probability of being included those postcodes that were[22] - 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.

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 local scheme. The prior hypothesis was that providers will have sought to include postcodes within a scheme where it was commercially attractive to do so with BDUK subsidy. This would imply a preference for locations where the required investment cost would be lower or where the anticipated demand for superfast broadband services was higher. The data available allowed us to consider the following characteristics of postcodes prior to the roll-out of the programme in 2013/14:

- NGA coverage in 2012 and 2013[23]: Pre-programme levels of connectivity were considered by including observations of NGA access in 2012 and 2013. Average and maximum available download speeds in 2013 were also included in some models. These gave a measure of pre-programme supply of superfast services.

- Percentage of postcodes within the LA and the Output Area with NGA access in 2012 and 2013: Analysis of the available data suggested that postcodes without NGA access were more likely to receive NGA access at a later stage if neighbouring postcodes had been enabled previously. This is suggestive that providers sought to deliver NGA deployments in spatial clusters, perhaps indicating that there are efficiencies to be gained from upgrading cabinets in proximity. 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 assumption 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. This expectation is borne out by the modelled average line lengths as set out in Table 2.1 .

- 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.

[22] Note that postcodes within the scope of local schemes, as defined by the SCT, but had not yet received a subsidised connection, have been included within the 'treatment group' for the purposes of this analysis.

[23] Initial models were developed that also included Average Download Speed in 2013 as a further control. However, there are a large number of missing cases and the data is truncated at 4MBits/s and 30MBits/s, resulting in a need to drop a large number of observations from the analysis.

- **Delivery points at the serving Cabinet and the serving Exchange:** The attractiveness of upgrading available broadband services to 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[24]:** 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, to which Virgin Media may have had no immediate plans to roll out superfast broadband services, competing providers may see an attraction 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[25].

- **Age of population –** the size of the resident population of working age and aged 65 and over[26] 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 was included[27] to provide these types of measure.

As noted, a matching approach will only be effective in providing an unbiased assessment of the impact of the programme if these characteristics described above 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 also will be other factors influencing the cost of installation that are not captured in the above, 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. It should also be noted that measures of local network characteristics are based on BDUK modelling rather than direct observation, which may also introduce an element of measurement error.

[24] Data was also available for the K-COM footprint, though no postcodes within the footprint received BDUK subsidies and as such did not assist in identifying postcodes sharing similar characteristics to those that did.

[25] An Output Area is spatial unit for reporting Census statistics equivalent to 10-12 postcodes).

[26] At an Output area level

[27] At a Local Authority level

Given these issues, the analysis focused primarily on drawing a counterfactual only from those postcodes which were identified as white in the Phase One and Phase Two Open Market Review process but were not included in the build plans of local schemes under either Phase. This produced a sample of 64,000 postcodes in total, relative to almost 330,000 postcodes included within build plans of either scheme. Ineligible postcodes ('grey,' 'black,' 'de-scoped and ineligible') were dropped from the comparison sample because they were thought to differ systematically from white postcodes in that commercial providers had signalled their intent to provide superfast broadband services to those postcodes without a subsidy.

3.2.1 Matching Models

The propensity score matching was completed using nearest neighbour techniques[28] in which each postcode within the build plans of funded schemes was matched to the postcode in the comparison sample with the closest propensity score. 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 associated with postcodes included within the build plans of funded schemes. Individual postcodes in the comparison sample were allowed to form a match with multiple postcodes that received BDUK subsidies. The matching process was completed for several subsamples, including postcodes that were in the build plans of Phase One and Phase Two schemes, and urban and rural areas separately.

The results of the initial probit models associated with a sample of matching models are set out in the Appendix (Tables A.1 and A.2). These show the findings from those models that excluded both average download speeds prior to the programme[29] and speed outcomes (average download speeds and maximum download speeds available) from the subsequent assessment of impact. These models maximised the available sample sizes for analysis, though other models were developed including these variables to test the sensitivity of results as explained below.

Table A.1 illustrates:

- The 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 average download speeds in 2013 were included as a matching variable in comparable models.

- However, the available data did not explain a high share of the variance in the decisions made by tenderers to include postcodes in the build plans of Phase One and Phase Two schemes (17 to 49 percent). Including additional information on average download speeds in 2013 did increase explanatory power, but only at the margin[30]. There is a risk that unobserved factors influenced the decision to include postcodes within the scope of local schemes. The degree to which this is consequential will depend on how far those factors are correlated with the outcomes of interest.

An overview of the resultant matched samples is provided in Table 3.2. The matching models reduced the level of mean standardised bias, i.e. the average percentage differences in the characteristics of the treatment and the comparison sample, to between 1.5 and 4.8 percent. The models were not fully effective in eliminating all observable differences between the

[28] Models were also developed using kernel and caliper matching though these did not improve the quality of results.

[29] With the exception of the model focusing on Phase Two, where the information available on broadband speeds in 2014 was much more comprehensive.

[30] The results of these models are not presented in the following two tables.

treatment and comparison samples. In particular, the models tended to produce a comparison sample with a smaller number of delivery points in the serving cabinet but a higher number of delivery points in serving exchange.

3.2.2 Findings

Comparisons between the matched treatment and comparison groups emerging from the analyses above were used to estimate the effect of the Superfast Broadband programme on NGA access, maximum available download speeds, the percent of premises with superfast (30Mbit/s) availability, and average download speeds. It should be noted that Connected Nations provides a measure of the share of premises on a postcode with superfast availability, but comparisons could produce misleading results if the programme had differential effects on postcodes with larger or smaller numbers of premises. To address this difficulty, an estimate of the number of premises with superfast availability on each postcode was derived by combining measures of the share of premises with superfast availability with estimates of the number of delivery points (as modelled by BDUK).

Table 3.3 below provides these results and includes the findings associated with model variants, illustrating the sensitivity of the results to:

- Inclusion of speed outcomes as outcome variables of interest (Models 2b, 3b, and 4b) – as postcodes for which data on these metrics are excluded, this reduces the available sample sizes for the analysis.
- Inclusion of average download speeds in 2013 as a matching variable (Models 2c, 3c and 4c) – again, as this was unobserved for a non-trivial number of postcodes, this also reduced the available sample sizes for analysis.

Table 3.1: Estimated Effect of Superfast on Connectivity Outcomes in 2016

Model	% of postcodes with NGA coverage	Max. Available Download Speeds (Mbit/s)	Superfast availability as % of premises	Average number of premises with superfast availability	Average Download Speeds (Mbit/s)
Phase One & Two Combined					
Model 2 [31]	25.1	-	27.0	3.51	-
Model 2b (speed outcomes included)	27.0	9.3	28.6	4.61	3.2
Model 2c (13 ave. d/l speeds included as control)	27.8	10.8	29.6	4.84	4.4
Phase One					
Model 3	33.0	-	34.5	4.60	-
Model 3b (speed outcomes included)	34.9	14.0	36.5	5.99	5.1
Model 3c (13 ave. d/l speeds included as control)	35.7	14.7	37.0	5.89	5.5
Phase Two					
Model 4	9.0	-	7.4	1.76	-
Model 4b (speed outcomes included)	9.6	-0.7*	7.3	1.95	-0.2*
Model 5 (Rural Postcodes)	31.4	11.0	33.7	5.52	4.4
Model 6 (Urban Postcodes)	15.6	5.8	18.9	3.84	0.8
Model 1 (using all unsubsidised postcodes as control)	11.6	-9.9	8.2	1.71	-4.2

Source: Ipsos MORI analysis,

Table note. Table shows difference between treatment and comparison samples in 2016, i.e. change attributable to the superfast programme according to the models. All effects reported in this table were significant at the 95 percent level except those marked with an asterisk.

The findings suggested that:

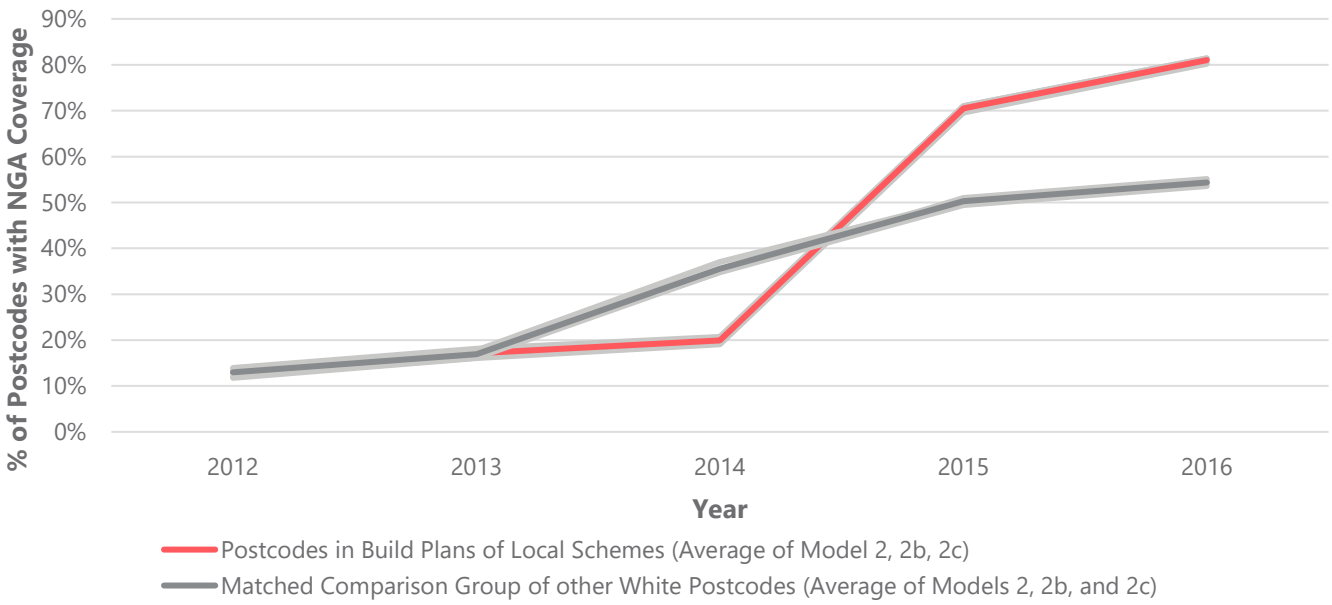
- Overall, the Superfast Broadband programme is estimated to have increased the share of postcodes with NGA access by 25 to 28 percentage points by 2016 as shown in Models 2 – 2c in Table 3.3. The programme is also estimated to have increased the share of premises with superfast access by 27 to 30 percentage points by 2016 (or an average increase in the number of premises able to receive superfast of 3.5 to 4.8).

[31] The results of this model were also reproduced excluding Swindon and Windsor and Maidenhead to test the robustness of findings to absence of data from suppliers that do not report information to Connected Nations. This suggested that these models may be understating the effect of the programme at the margin, with an estimated effect on the share of postcodes with NGA coverage of 25.5 percentage points, and the average share of premises with superfast availability of 27.6 percentage points.

- Average maximum download speeds are estimated to have increased by 9 to 11Mbit/s because of the programme by 2016, while average download speeds are estimated increased by 3 to 4Mbit/s (an effect of 26 percent) over the same period.

- The estimated effect of the programme on NGA coverage over time is illustrated in Figure 3.1, which shows the average of Models 2 – 2c. This figures suggests that while the programme led to a substantial extension of NGA coverage from 2015 onwards, this came at the cost of delayed roll-out to those areas that would have otherwise received improved connectivity without the programme in 2014. One possible explanation is that this delay was caused by the time absorbed by the Open Market Review, tendering and contracting processes, on the assumption that providers would have been unlikely to have committed investment to those postcodes until these processes were complete.

Figure 3.1: Estimated Effects of the Superfast Broadband Programme on Percentage of Postcodes Covered by NGA, 2012 to 2016



Source: Ipsos MORI analysis

Figure note. Graph shows averages of Models 2, 2b, and 2c reported above. Light grey lines show individual results of Models 2, 2b, and 2c.

- Phase One of the programme is estimated to have increased the share of subsidised postcodes with NGA access by 33 to 36 percentage points and the average share of premises with superfast access by 35 to 37 percentage points (an increase in the average number of premises able to receive superfast of 4.6 to 6.0).

- The smaller Phase Two programme was estimated to have more modest effects on NGA access and superfast availability and no effect on maximum available or average download speeds. As highlighted in the preceding section, delivery of Phase Two had only just started in many areas, explaining the smaller size of the estimated effects. However, effects may also be understated because speeds are observed at the postcode level. To the degree that Phase Two focused on enabling premises on postcodes where other properties already benefitted from faster speeds, the presence of those other properties would mask the effect of the programme in measures of NGA coverage.

- The estimated effects of the programme were also larger in rural areas than in urban areas, which is unsurprising given the focus of delivery on rural areas.

- In all sets of findings, the effect of the programme on the share on superfast availability was larger than the effect of the programme on NGA access. This suggests that in the absence of the programme, it is likely that some of the postcodes benefitting from BDUK investment would have benefitted from some form of enhanced technology without the subsidies, though not to superfast speeds.

- The table also illustrates estimated effects when all unsubsidised postcodes are included in the analysis (Model 1). As expected, the estimated impacts of the programme on NGA and superfast are smaller than for those models using only other white postcodes as a control. The results do not offer a consistent view of the impacts of the programme, suggesting the programme simultaneously had a positive effect on NGA and superfast availability while reducing maximum and average download speeds.

3.2.3 Unsuccessful tenders

Subsidies allocated through the programme were awarded through a competitive procurement process. As each tender defines the set of postcodes the prospective provider intended to upgrade, it would be in principle possible to define a set of unsubsidised white postcodes that were deemed commercially viable with subsidy by at least one provider where unsuccessful tenders did not overlap with the tender that was ultimately successful. This group of white postcodes could be assumed to be more similar those included within the build plans of local schemes than the general population of white postcodes that were included in the analyses above.

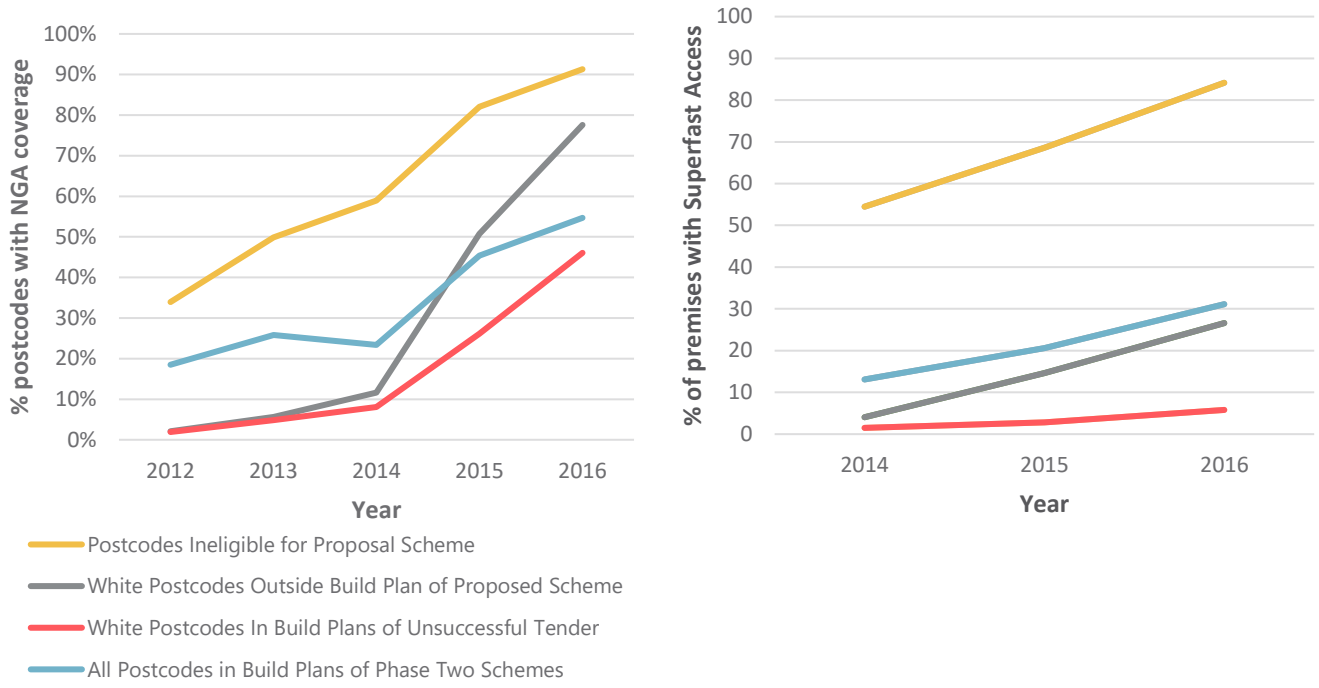
The SCT associated with a single unsuccessful tender for a proposed Phase Two scheme was available for analysis. Discussions with BDUK indicated that the tender was rejected because the proposal did not involve a sufficient focus on priority areas for the local authority and there was no successful tenderer for the scheme, although the local authority did pursue another scheme in another part of the county. While care needs to be taken to avoid extrapolating from this single case, the circumstances involved are likely to give a clearer indication of the coverage the market may have delivered in the absence of public intervention (at least at this location).

The SCT in question covered 64,788 postcodes in the local authority. Most of these (53,003, or 82 percent) were designated as grey or black postcodes that were ineligible for BDUK subsidies. Of the remaining 11,785 postcodes (18 percent), 5,205 were included within the build plan of the proposed scheme. Figure 3.2 below illustrates the evolution of NGA coverage and superfast (30Mbit/s) between 2012 and 2016 in each of these types of postcode:

- Changes in NGA and superfast coverage: NGA coverage rose from 5 percent to 45 percent between 2012 and 2016 within the postcodes covered by the build plan of the proposed scheme. Superfast (30Mbit/s) availability remained low, rising from an average of 2 to 6 percent of premises between 2014 and 2016. This suggests that the market brought forward some form of enhanced connectivity without the subsidies made available through the programme, though not necessarily at the superfast speeds being targeted.

- Comparisons to other postcodes in build plans of funded Phase Two schemes: NGA coverage rose from 26 percent to 55 percent of postcodes in the build plans of Phase Two schemes that were funded between 2012 and 2016. The share of premises with superfast availability rose from 20 percent to 31 percent between 2014 and 2016.

Figure 3.2: NGA Coverage and Percentage of Premises with Superfast Access, 2014 to 2016, Postcodes Included in the Build Plan of an Unsuccessful Phase Two Tender



Source: Connected Nations, Ofcom and SCT associated with unsuccessful tender, Ipsos MORI analysis

Given the systematic differences in baseline levels of connectivity between the two types of area, general comparisons between the postcodes covered by the build plans of declined proposal and funded Phase Two schemes do not offer a clear view on the effects of the programme, To better understand the impact of the subsidies in this case, a propensity score matching approach was applied in which the white postcodes within the build plan of the proposed scheme were matched to postcodes that were included within the build plans of funded Phase Two schemes. This involved using the same set of matching variable as for the preceding set of analysis.

The matched sample of postcodes included in the build plans of funded Phase Two schemes closely matched the characteristics except in the following respects:

- The average modelled length of the line to the serving exchange (at 3,723m) was higher in those postcodes included in the build plan of the unfunded tender than in comparable postcodes included in the build plans of Phase Two schemes (3,515m). Correspondingly, modelled predicted final download speeds were lower for postcodes included in the build plan of the unfunded tender relative to similar postcodes included in the build plans of funded Phase Two schemes. This may suggest that postcodes in the build plan of the unfunded tender were of lower commercial viability than otherwise similar postcodes in the build plans of Phase Two schemes.

- The total population of both working age and those aged 65 plus was higher in those postcodes included in the build plan of the unfunded tender than in comparable postcodes included in the build plans of Phase Two schemes. This did not, however, apply to population density.

- The local economies covered by the unfunded tender were apparently weaker than the areas covered by otherwise similar Phase Two schemes, with lower gross average weekly pay, lower employment rates and higher unemployment

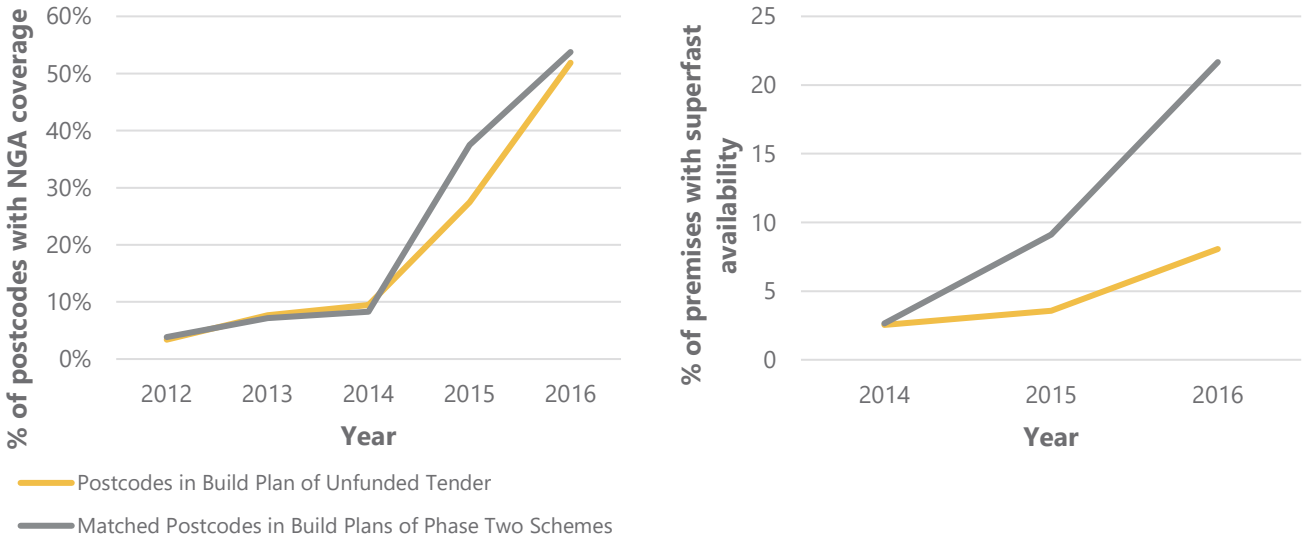
rates. As such, this could have lowered expectations around levels of demand, though as outlined above, suppliers adopted invariant assumptions around demand and these factors may not have influenced decisions to include these postcodes in the build plan.

Figure 3.3 below shows the estimated effect of subsidies and shows a broadly similar pattern of results to those set out in the preceding section for Phase Two:

- Effect on NGA access: The percentage of postcodes with NGA access rose from three percent in 2012 to 52 percent in 2016 in those areas covered by the proposed (but unfunded) scheme, while rising from three percent to 54 percent in comparable postcodes included in the build plans of Phase Two schemes. Differences in NGA coverage were not statistically significant in 2016, although NGA coverage came forward more rapidly on those postcodes benefitting from BDUK subsidies.

- Effect on superfast availability: The average share of premises with access to superfast (30Mbit/s) rose from three percent in 2014 to eight percent in 2016 on the postcodes included in the build plan proposed in the unfunded scheme, while rising from three percent to 22 percent in comparable postcodes included in the build plans of funded schemes (implying an impact on superfast availability of 14 percentage points). This aligns with the results set out above that suggest that while some postcodes included in the build plans of Phase Two schemes may have otherwise received NGA coverage (albeit at a later point in time), superfast speeds would have remained inaccessible.

Figure 3.3: Estimated Impact of the Superfast Broadband Programme on NGA Coverage and Superfast Availability, Postcodes in Build Plans of Unfunded Tenders vs Comparable Postcodes in Phase Two Build Plans



Source: Ipsos MORI analysis

3.2.4 Additionality

The results set out above can be used to the estimate the number of postcodes or premises enabled with superfast coverage that would not have received enhanced connectivity without the programme, by multiplying the total number of postcode in the build plans of funded schemes by the estimated increase in the average number of premises with access to superfast broadband services attributable to the programme. Table 3.4 sets out these estimates drawing on the variety of estimates of the effects of the programme set out in Table 3.3 and in Figure 3.3 above.

Overall, the programme is estimated to have resulted in 1.2m to 1.7m additional premises receiving superfast coverage that would not have done without the programme by June 2016, in the sample of postcodes covered by this analysis. It is important to note that this estimate will not capture the full effect of the programme to the degree that it had a role in accelerating superfast coverage, resulting in some premises receiving superfast coverage earlier than they would have done without the subsidy. The results set out elsewhere also highlight the problem of recording lags in which the improvements in connectivity delivered by the programme do not appear immediately in the Connected Nations data (see Figure 2.4). This will have tended to understate the impact of the Phase Two as the bulk of delivery has took place in 2016. Moreover, the full impact of subsidised coverage will only be visible in the 2017 Connected Nations report, which was not available at the time of writing.

Table 3.2: Estimated Number of Premises Receiving Superfast Coverage by 2016 as a Result of the Superfast Broadband Programme, Propensity Score Matching Results

Area	Number of Postcodes	Estimated effect on the average number of premises with superfast coverage by 2016		Estimated number of additional premises with superfast coverage by 2016	
		Low	High	Low	High
Postcodes in build plans of Phase One and Two schemes	346596	3.51	4.84	1,216,552	1,677,525
Postcodes in build plans of Phase One schemes only	292742	4.60	5.99	1,346,613	1,753,525
Postcodes in build plans of Phase Two schemes only	87861	1.76	1.95	154,635	171,329
Phase Two postcodes matched to unfunded tender	2184		2.7		5,897

Source: Ipsos MORI analysis.

Table Note. There is some overlap between the build plans of Phase One and Phase Two schemes and estimates of the effects on Phase One and Phase Two cannot be added together to provide an alternative estimate of the total effect of the programme. Esimates of effects relate only to those local schemes for which a SCT was available.

The findings can be compared to the gross number of premises receiving superfast coverage (30Mbit/s and above) subsidised by the programme to reach an estimate of the level of additionality associated with the subsidised coverage, i.e. the share of premises receiving subsidised coverage that would not have received superfast coverage otherwise. These finding are set out in the following table.

Table 3.3: Estimated Additionality – share of premises receiving subsidised coverage that would not have received superfast coverage without the programme

Area	No. of premises receiving subsidised coverage by June 2016	No. of premises receiving subsidised 30Mbit/s coverage by June 2016	Estimated number of additional premises with superfast coverage by 2016		Estimated Additionality (%)	
			Low	High	Low	High
Postcodes in build plans of Phase One and Two schemes	3,210,002	3,085,649	1,216,552	1,677,525	39	54
Postcodes in build plans of Phase One schemes only	3,119,651	2,997,009	1,346,613	1,753,525	45	59
Postcodes in build plans of Phase Two schemes only (2015 onwards)	286,124	274,275	154,635	171,329	56	62
Phase Two postcodes matched to unfunded tender	7,793	7,220		4,243		59

Source: Ipsos MORI analysis.

Table Note.There is some overlap between the build plans of Phase One and Phase Two schemes and estimates of the effects on Phase One and Phase Two cannot be added together to provide an alternative estimate of the total effect of the programme. Esimates of effects relate only to those local schemes for which a SCT was available.

- Overall additionality from PSM findings: The programme is estimated to have upgraded 3.1m premises with predicted download speeds of 30Mbit/s or more on postcodes within the scope of this analysis, i.e. areas for which SCTs are available). The results suggested that 1.2m to 1.7m premises would not have received superfast coverage by 2016 in the absence of the programme, giving an overall range for the rate of additionality of 39 to 54 percent.

- Phase One and Phase Two: The estimated additionality of subsidised superfast coverage that had come forward on the postcodes within the build plans of Phase One schemes was lower than for postcodes within the build plans of Phase Two schemes (between 39 and 54 percent for Phase One and 56 to 62 percent for Phase Two). However, it should be noted that the effects of the two phase cannot be properly separated using this approach as some postcodes benefitted from subsidised coverage under both Phase One and Phase Two.

- Analysis of unfunded Phase Two tender using PSM: Analysis of the unfunded tender in Phase Two is thought to offer a more robust assessment of the impacts involved, and suggests a rate of additionality associated with subsidised superfast coverage of 59 percent. This is considered a more robust result as the approach will both better address unobserved factors driving the selection of postcodes into the scheme, and there was no contamination of the results from build under Phase One. However, the findings are specific to the locality and there may be issues in generalising this result to Phase Two schemes overall.

3.3 Longitudinal Panel Models

The matching models above are not robust to unobserved differences between subsidised and unsubsidised postcodes that could lead to biased findings. A supplementary set of analyses were developed to exploit the longitudinal nature of the data available to explore the possible effect of these unobserved factors on the estimated impact of the programme. This involved

the estimation of the following econometric model describing the relationship between the number of premises receiving subsidised superfast coverage through the programme and the number of premises with NGA access[32]:

$$NGA_{it} = \alpha + \beta X_{i,2013} + \gamma C_{it} + \theta t + \alpha^{i} + \alpha^{L} t + \alpha^{T} + \alpha^{L} \alpha^{t} + \varepsilon_{it}$$

This model describes the number of premises with NGA access in area i in period t (NGA_{it}) as a function of a set of observable characteristics of an area before the programme began ($X_{i,2013}$) and the cumulative number of premises receiving subsidised coverage within the area in the period (C_{it}). The model also allows for national trends that might influence NGA coverage across all areas (t). 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 ($\alpha^{L} \alpha^{t}$). The parameter γ gives a direct measure of the additionality associated with the programme, i.e. the proportion of premises receiving subsidised coverage that would not have received NGA coverage in the absence of the programme.

To facilitate the estimation of the model, the equation above was specified in first-differences as specified below.

$$\Delta NGA_{it} = \gamma \Delta C_{it} + \theta \Delta t + \alpha^{L} \Delta t + \alpha^{T} + \alpha^{L} \alpha^{T} + \varepsilon_{it}$$

This transformation relates the change in the number of premises with NGA access to the number of premises receiving subsidised coverage within the year. The transformation also results in fixed characteristics of areas being dropping out of the model - including the pre-treatment characteristics of the model – but importantly, differencing in this way means that the results will not be biased because of their omission. However, in some models, these controls were reintroduced to explicitly capture any unobserved trend effects affecting areas with different pre-programme characteristics.

- Output area: To facilitate the estimation of the model, the postcode level data driving the preceding analysis was aggregated to an Output Area level (see footnote 23).

- Number of delivery points with NGA coverage: The number of premises with NGA coverage required approximation from the available data. As highlighted in Section 1, the Connected Nations data provides a binary measure of whether a postcode was covered by NGA in 2012 and 2013 and measures of NGA coverage from 2014 onwards required adaptation to provide a consistent measure over time. This binary measure was multiplied by the number of delivery points on the postcode to estimate the total number of premises with NGA coverage at a postcode level, i.e. prior to aggregation[33].

- Controls: The same set of pre-programme area level controls employed in the propensity score matching models were employed in the analysis.

- Maximum NGA coverage: The number of premises with NGA coverage cannot expand beyond the number of premises within a postcode, i.e. once all premises within an area have access to next generation technology, this measure cannot grow further. Comparisons between areas benefitting from subsidised connections and those with complete NGA coverage will lead to an overstatement of the impact of the programme. This complication was avoided by excluding

[32] The focus of the analysis is on NGA access as this is the only measure for which data is available continuously between 2012 and 2016.

[33] The number of delivery points on the postcode is treated as fixed in 2013 to avoid any possible complications that may arise should enhanced connectivity delivered through the programme encourage further residential or commercial development.

any area from the analysis from the year after NGA coverage reached 100 percent. Any output area where NGA coverage was 100 percent in 2012 were excluded from the analysis altogether.

- **Ineligible areas:** In most analyses, Output Areas within the boundaries of local authorities that were ineligible for the programme were excluded owing to concerns that these areas differed systematically from eligible areas.

3.3.1 Results

The findings of these models are set out in the table below. A simple first difference model produce an estimated increase in NGA coverage of 0.77 premises for each premise receiving subsidised coverage through the programme, i.e. 77 percent additionality. Excluding those output areas reaching 100 percent NGA coverage reduces this estimated effect to 0.72 (as expected), though excluding ineligible areas has no further effect on results. Allowing for unobserved local authority level trends, time-specific shocks affecting all areas, and time-specific shocks at a local authority level further reduces the estimated effect to 0.63. This result implies a higher rate of additionality than estimated using the matching models set out above and the estimated additionality of coverage delivered under Phase One and Phase Two was broadly equivalent.

Table 3.4: Estimated Impacts – Longitudinal Panel Models

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Change in NGA covered premises per premises receiving subsidised coverage	0.77	0.72	0.72	0.63	0.63	
Change in NGA covered premises per premises receiving subsidised coverage under Phase One	-	-	-	-	-	0.63
Change in NGA covered premises per premises receiving subsidised coverage under Phase Two	-	-	-	-	-	0.59
Areas reaching 100% NGA coverage excluded?	No	Yes	Yes	Yes	Yes	Yes
Eligible areas excluded?	No	No	Yes	Yes	Yes	Yes
Fixed effects	No	No	No	Yes	Yes	Yes
2013 Output Area controls	No	No	No	No	Yes	Yes
Adjusted R-squared	0.2453	0.2294	0.2530	0.3599	0.3923	0.3851
Number of observations	861,211	295,107	263,724	263,724	252,890	252,890

Source: Ipsos MORI analysis.

Table Note. Estimated model coefficients were significant at the 99% level in all cases.

The results above only compare changes in NGA 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 above pointed to a possible effect whereby the Open Market Review, consultation, tendering and contracting process 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, figure 2.4 suggests that 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 (the panel data only included five years so it was not possible to include more lags within the models to explore longer term effects):

$$\Delta NGA_{it} = \gamma^1 \Delta C_{it+1} + \gamma^2 \Delta C_{it} + \gamma^3 \Delta C_{it-1} + \gamma^4 \Delta C_{it-2} + \theta \Delta t + \alpha^L \Delta t + \alpha^T + \alpha^L \alpha^T + \varepsilon_{it}$$

The results are set out in the table below and suggest that the scheme did have a negative effect on NGA availability in the year before premises received subsidised coverage were delivered (equivalent to nine premises per 100 connections). However, the estimates suggested that in the year following the delivery of subsidised coverage, 0.75 additional premises received NGA coverage per premises upgraded (75 percent additionality). However, the results also suggested that 23 percent of premises receiving subsidised connections would have received NGA coverage anyway but two years later. This gives overall additionality of 50 percent over the four-year period, which is consistent with the estimates of the matching models.

The results show a similar pattern for connections delivered through Phase One. It was not possible to estimate an effect lagged by two years for Phase Two. The declining rate of additionality may also explain the pattern from the matching models that suggested that additionality in 2016 was higher for premises upgraded in Phase Two than for those upgraded under Phase One, as the former were upgraded more recently. It should be noted that the estimated rate of additionality of premises upgraded over two years was approximately 80 percent of those estimated for Phase One (with an increase in premises passed by NGA of 0.62 per premises upgraded under Phase Two in comparison to 0.76 under Phase One). This is possibly suggestive of lower rates of additionality overall for Phase Two, though the analysis only covers a small share of activity that will be funded under Phase Two schemes and may not be representative.

Table 3.5: Estimated Additionality Over Time – Longitudinal Panel Models

	Overall	Phase One	Phase Two
Change in NGA covered premises per premises receiving subsidised coverage (T+1)	-0.09	-0.09	-0.14
Change in NGA covered premises per premises receiving subsidised coverage (T)	0.60	0.60	0.21
Change in NGA covered premises per premises receiving subsidised coverage (T-1)	0.25	0.25	0.55
Change in NGA covered premises per premises receiving subsidised coverage (T-2)	-0.23	-0.23	-
Total effect 2 years post delivery	**0.53**	**0.53**	**0.62**
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
R-squared	0.4783	0.4784	
Number of observations	130,767	130,767	

3.4 Regression Discontinuity Design

As highlighted in Section 3.2, the Propensity Score Matching strategy developed is not robust to unobserved differences between postcodes that did and did not receive BDUK subsidies. To provide a further cross check on results, and to help discriminate between competing models, Regression Discontinuity Design methods were applied to assess the impacts of the programme on NGA coverage, available speeds, and take-up. These approaches involve exploiting the availability of eight local authority areas that were ineligible for subsidies through the Superfast Broadband programme, comparing postcodes on either side of the local authority boundary to give an estimate of impact that is robust to both observable and unobservable differences between areas.

3.4.1 Overview

Eight local authorities were deemed ineligible for BDUK subsidies because it was considered that commercial deployment of the technology would be extensive or because the local authorities chose not to take part. This included seven urban local authorities: Birmingham, Bristol, Coventry, Kingston-upon-Hull, Manchester, Portsmouth, Salford, and Southampton. The Greater London Authority area was also deemed ineligible.

Given the reasons for excluding these areas from the programme, it might be expected that these ineligible areas would differ in systematic ways from eligible areas and be unsuitable as a comparison group for eligible areas. The scope of commercial plans in these areas suggests that these areas may have been amongst the most commercially attractive, and comparisons between ineligible and eligible areas have the potential to understate the impact of subsidies in bringing forward superfast connectivity.

However, if local authority boundaries are arbitrary with respect to the roll-out of superfast broadband infrastructure, postcodes in the immediate neighbourhood of those boundaries might be thought to be essentially equivalent. If so, then differences between them would be effectively random in nature and comparisons between those postcodes just inside and just outside those boundaries could approximate the design of a Randomised Control Trial. This approach a form of Regression Discontinuity Design) is potentially robust to both observed and unobserved differences between postcodes as they are assumed to be randomly distributed at the boundary. However, the approach has a low level of external validity in that the findings only apply to areas located at the boundary (and impacts may be very different in other locations). In light of this, the application of RDD methods was suggested just as a means of cross-checking the results of other analyses and discriminating between competing results.

3.4.2 Econometric model

The RDD approach has been applied by focusing the analysis on a set of postcodes within 1km of each ineligible local authority to concentrate the analysis on changes that occurred at the boundary. Two types of adjustment were made in light of the specific spatial characteristics of the ineligible areas under consideration:

- As Manchester and Salford share a boundary, they were pooled and treated as single area.
- Three of the local authorities had a boundary with the sea (Kingston-upon-Hull, Portsmouth, and Southampton). Their inclusion would potentially violate the assumption that differences between postcodes are random, as there are no eligible postcodes located within a short distance of these boundaries. This issue was dealt with by removing the sea border from the local authority boundary, so that distances were only calculated to the nearest land boundary.

To implement the RDD, a flexible parametric model was applied relating the outcomes of interest (Y) in postcode i to its distance from the boundary (D):

$$Y_i = \alpha + \beta T_i + (1 - T_i) \cdot (\delta_1 D_i + \delta_2 D_i^2 + \delta_3 D_i^3) + T \cdot (\delta_4 D + \delta_5 D_i^2 + \delta_6 D_i^2) + u_i$$

In this model, T is a dummy variable taking the value of 1 if the postcode is eligible for BDUK subsidies, and 0 otherwise. The parameter β captures any discontinuity in the outcome variable as one crosses the boundary (i.e. at D = 0), which is interpreted as the causal effect of the programme.

The model was estimated three times in each case, using a linear, quadratic and cubic specification (the equation sets out the cubic specification, with the quadratic and linear models involving dropping the cubed and squared terms of the distance variables). This flexible approach allowed the shape of the function to vary on either side of the boundary, to explore uncertainties with regard to the shape of the objective function on each side of the threshold. The model was estimated using OLS – except where the outcome of interest was NGA coverage, where logistic regression was employed, reflecting the binary nature of this outcome.

The models were applied to test the effect of the programme on the following outcomes of interest (derived from the Ofcom Connected Nations report):

- Next Generation Access (NGA) coverage in 2016. The 2016 Connected Nations report expresses this as a percentage of premises on the postcode, and was converted to a binary measure by assuming a postcode was passed by NGA coverage if more than 50 percent of premises were passed by the NGA and not otherwise.
- Log of maximum download speeds in Mbit/s in 2016.
- Log of average download speeds in Mbit/s in 2016.

Distances from the boundaries of local authority were calculated using the easting and northing co-ordinates taken from the Office for National Statistics postcode file. Postcodes were dropped if they did not appear in the Ofcom Connected Nations report (the latter excludes postcodes with no premises, such as postcodes for statues and other postal addresses with no associated premises).

3.4.3 Validity checks

The validity of the RDD method depends on an assumption that there are no other discontinuous changes in relevant co-variates at the boundary. In this case, there may be several reasons why this assumption may not hold. Broadband providers may require planning permissions to install new broadband infrastructure if it requires a new cabinet to be installed. Additionally, local authorities may have pursued other funding routes to support delivery of superfast broadband infrastructure within their boundaries independently of the Superfast Broadband programme. Both of these cases have the potential to produce discontinuous changes at the boundaries of the local authority that are connected with the outcomes of interest, violating the assumption that areas on either side of the boundary are equivalent.

The validity of the required assumptions was tested by applying the RDD model to NGA coverage in 2012. If there were no significant differences, a further check was made on average download speeds in 2012. At this stage, there had been no delivery of the Superfast Broadband Programme and if the required assumptions hold there should be no significant differences in either of these measures prior to the commencement of the programme. The results of these validity tests suggested:

- **Valid areas:** The models suggested that there were no statistically significant differences in NGA coverage or average download speeds at the boundaries of London, Portsmouth and Kingston-upon-Hull. However, there was no delivery of the Superfast Broadband programme within 1km of the boundary of Portsmouth and Kingston-upon-Hull. In the latter case this was due to the footprint of K-COM extending beyond the local authority boundary. As such, only London offered a useful test case for the analysis.

- **Invalid areas:** The models indicated that there were discontinuous changes in those variables at the boundaries of Birmingham, Bristol, Coventry, Manchester and Salford, and Southampton. There was no statistically significant difference in NGA coverage in Southampton, but there were significant differences in average download speeds. Analyses of these areas was not taken any further.

The results of validity checks for London are set out in the figure below (linear models only).

Figure 3.4: RDD Validity Check, London, NGA Coverage and Average Download Speeds 2012

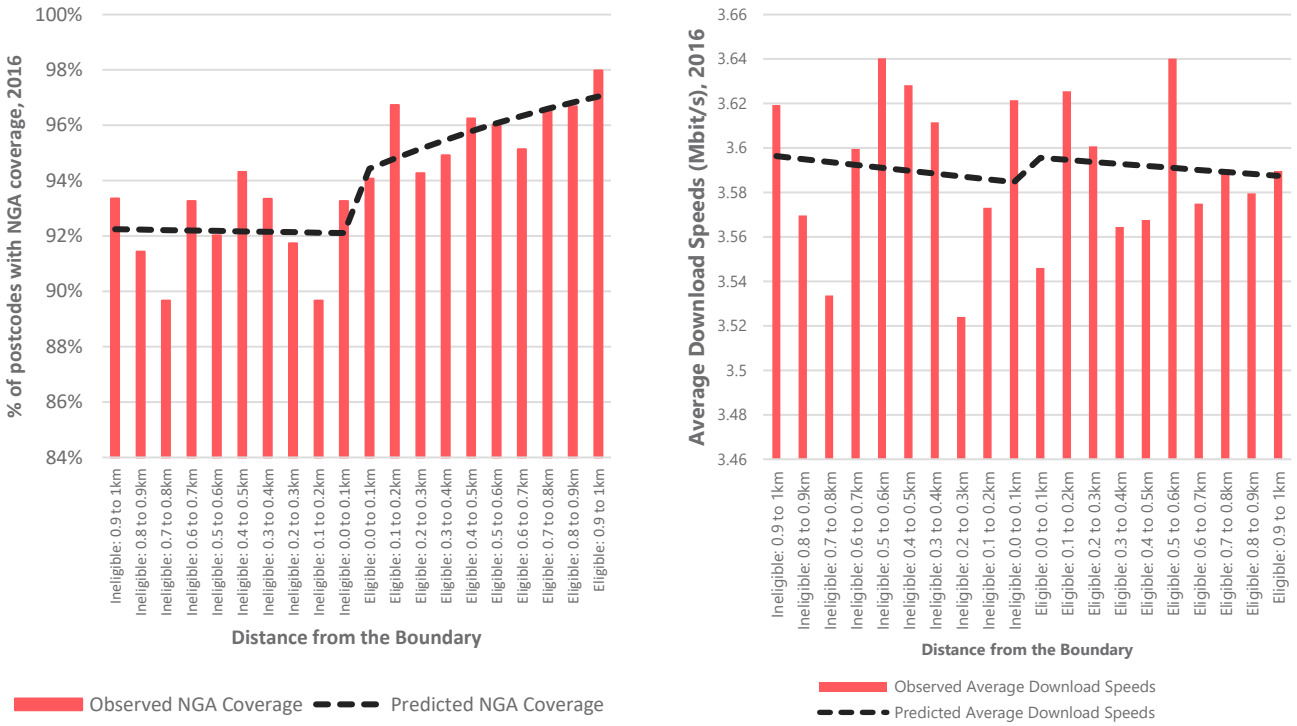
3.4.4 Results for London

The results found a statistically significant effect on NGA coverage at the boundary of London. This effect was equivalent to two percentage points in the linear model, four percentage points in the quadratic model and six percentage points in cubic model. These effects were relatively small in magnitude – though this was expected as NGA coverage rates in 2012 were already high (at circa 88 percent). No effects on maximum download speeds or average download speeds were found in the models. Again, given the relatively the relative small effects on NGA coverage, this result is not unexpected.

To explore the relationship between the above findings and delivery of the programme, it was assumed that the estimated effects were valid up to 100 metres from the boundary of the local authority to derive an estimate of the number of additional postcodes enabled with NGA access as a result of the programme. This was compared with the number of postcodes receiving BDUK subsidies (derived from the C3 reports) to provide some insight into additionality.

There were 270 postcodes within 100 metres of the boundary of London, giving an estimate of the number of additional postcodes receiving NGA coverage that would not have done so without the programme of between six and 15 by June 2016, i.e. 270 multiplied by 0.02 to 0.06. BDUK monitoring information suggests that a total of 17 postcodes received subsidised coverage in this region, suggesting additionality of between 34 and 87 percent. The results of other analyses lie within the centre of this range, giving some further validation of the general findings.

Figure 3.5: RDD Results, London, NGA Coverage and Average Download Speeds 2016



3.5 Crowding Out

The final analysis focused on exploring the extent to which the delivery of subsidised coverage led to any effects on grey, black or otherwise ineligible postcodes that were not included within the scope of the schemes funded. As argued above, negative effects on the emergence of NGA coverage could be expected if the delivery of the programme diverted scarce resources – such as skilled labour or capital – away from areas in which providers planned to install enhanced infrastructure without subsidy. However, as highlighted in the theory of change, 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 making the assumption that any effects of this nature were likely to be experienced at the local level. While telecoms suppliers operate national supply chains, the delivery of construction activity tends to be by local contractors. 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 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[34] (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. A positive coefficient is a signal of crowding-in and a negative coefficient is a signal of crowding out.

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:

$$\Delta NGA_{jt} = \sum_{k=1}^{5} \gamma_k \Delta C_{kt} + \theta \Delta t + \alpha^L t + \alpha^{\mathrm{T}} + \alpha^L \alpha^t + \varepsilon_{it}$$

Any LSOAs without any grey, black, or otherwise ineligible postcodes were removed from the sample. Additionally, if NGA 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).

3.5.1 Results

The findings are set out in Table 3.8 below and suggest that while the programme may have altered the spatial distribution of NGA coverage at the margins, any effects were trivial and limited to the short term. The models suggested the possibility of a small crowding out effects at distances of up to 10km subsidised postcodes in the year of delivery, with counterbalancing positive effects at distances of 20km to 30km. Models including lagged effects suggest that these effects only endured for one year, and there may have even been small positive effects on NGA coverage after one year.

[34] 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 3.6: Estimated Level of Crowding Out

	Model 1	Model 2	
	No lagged effects	Effect in Year t	Effect in Year t+1
Change in NGA covered premises per premises receiving subsidised coverage within:			
0-10km	-0.0010**	-0.00111**	-0.00073
10-20km	0.0001	-0.00004	0.00046
20-30km	0.0000	-0.00019	0.00117**
30-40km	0.0007**	0.00057**	0.00021
40-50km	0.0003	0.00024	0.00008
Total effect (significant effects only)	-0.0003	0.0006	
R-squared	0.233	0.4769	
Number of observations	66,293	130,507	

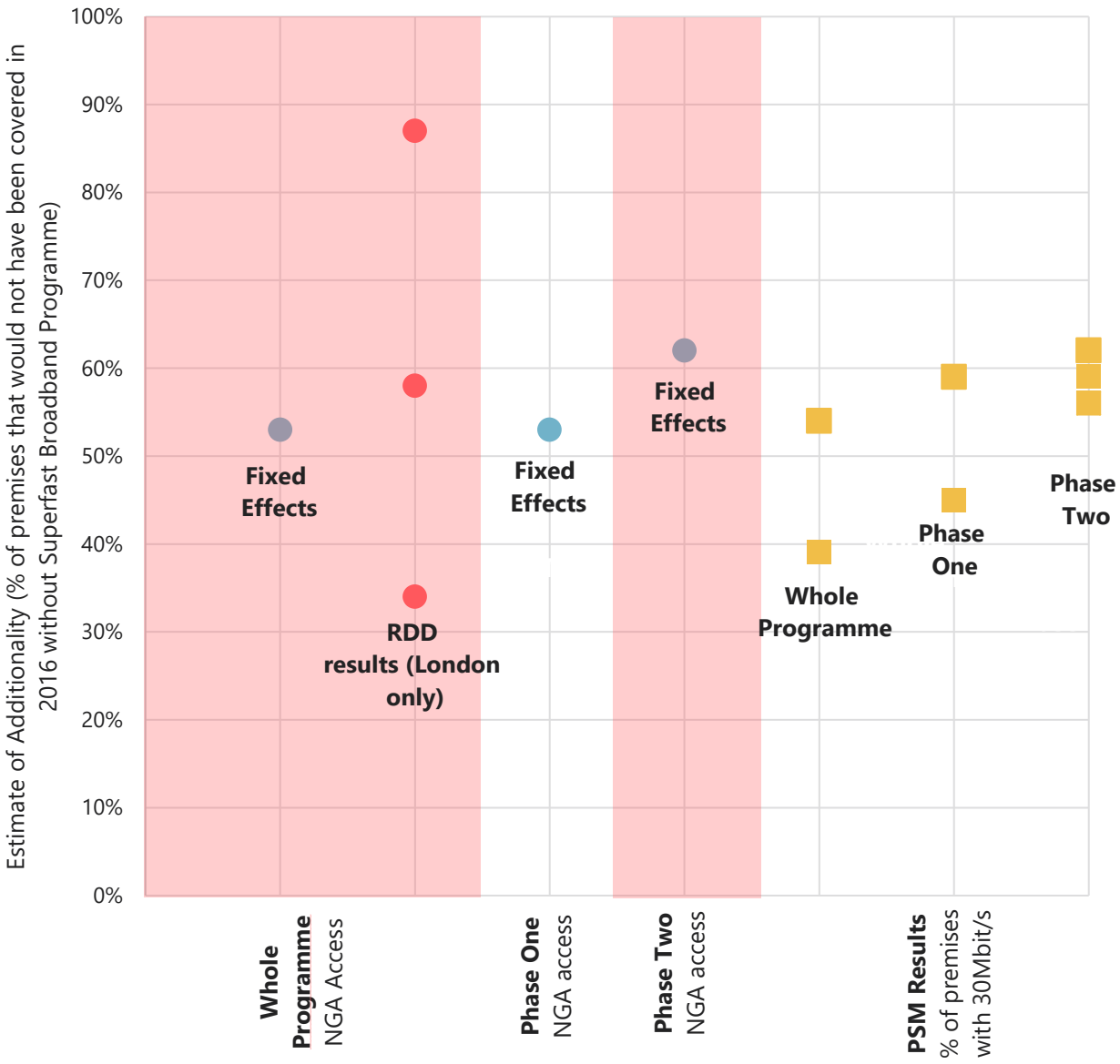
*Source: Ipsos MORI analysis, ** indicates the coefficient estimate was significant at the 99 percent level.*

3.6 Summary

3.6.1 Additionality at 2016

The following figure provides an overview of the findings of the above analyses in terms of the implied additionality of subsidised coverage by 2016, i.e. the proportion of premises that would not have received superfast coverage in the absence of programme. As illustrated in the figure 3.6, there is a reasonable degree of consistency across the results produced by the different analyses – with all results (aside from the outlying results from the RDD analysis) lying within a range of 39 to 62 percent.

Figure 3.6: Estimates of Additionality of NGA Coverage and 30Mbit/s Connections in 2016



3.6.2 Additionality over Time

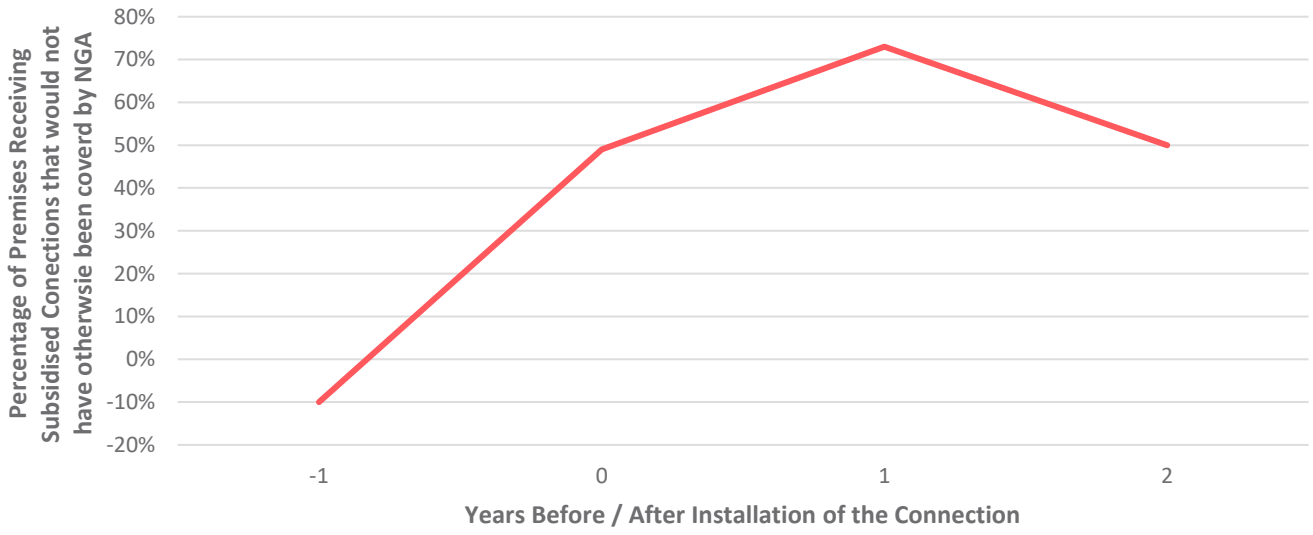
The findings above provide an assessment of additionality at a particular point in time (June 2016) but do not capture the apparent effect of the programme in accelerating access to superfast connectivity. The figure below provides an estimate of the rate of additionality over time (drawing on the results set out in Table 3.6) – and suggest that while additionality is 53 percent two years following the installation of the connection, around 25 percent of premises receiving subsidised connections did so one to two years earlier that they would have otherwise.

This finding aligns with the wider pattern of results – the high rate of additionality estimated in the short term (up to 73 percent) suggests that the Open Market Review process was effective in encouraging providers to reveal their immediate commercial plans and declining additionality in the longer term is interpreted as an indicator that commercial plans evolved while the programme was delivered. This is supported by the wider evidence – providers underestimated the demand for the technology (which also increased over the course of the programme) and overestimated the cost of installation. These

changes in market conditions will likely have influenced commercial plans - encouraging providers to invest in locations they may not have considered in 2013 or 2014.

The above explanation also raises a question regarding the possible demonstration effects of the programme. It is possible that Phase One of the programme led to a process of demand and cost discovery, demonstrating the viability of the locations previously thought to be unviable. If this type of process led to further unsubsidised investment in superfast coverage then the findings set out in the paper will understate the level of additionality associated with the programme. However, it would not be possible to assess the presence or magnitude of these types of effect given the data available.

Figure 3.7: Estimates of Additionality of NGA Coverage over time



Source: Ipsos MORI analysis

3.6.3 Cost Effectiveness

The section sets out a cost-effectiveness analysis of the programme – relating the expected net subsidy associated with the programme to the number of additional connections delivered. For the purposes of these analyses, we assume an additionality rate of 60 percent. This is based on the average additionality of NGA coverage post installation (60 percent) rather than additionality in 2016 (53 percent), and assumes that the estimated effects can be extended to the areas that have been excluded from the analysis.

As set out in the table below – on the basis of these assumptions, the programme is projected to result in 3.2m additional premises[35] receiving access to superfast connectivity at a net public subsidy per premise connected of £352 (on a present value basis, in 2016/17 prices). This is only 16 percent higher than the unit cost associated contracted (£297 per connection on a per premises basis, in 2016/17 prices). The role of the underspend and take-up gainshare mechanisms in protecting the value for money associated with the programme was significant and in some ways, could be interpreted as having raised the rate of additionality from 60 to 84 percent. In the absence of these protections, the estimated unit cost would have risen

[35] Applying 60% additionality to the 5.3m premises connected.

by 40 percent to around £494 per net additional premises connected (with 67 percent of this difference driven by take-up gainshare mechanism).

Table 3.7: Estimated Net Cost per Additional Premises Upgraded (present value in 2013 at 2016/17 prices)

	Gross Public Subsidy per Gross Premises Upgraded	Net Public Subsidy per Additional Premises Upgraded
Present value of public spending in 2017 (£m)	1,582	1,127
Connections Contracted	5,333,681	3,200,209
Public spending per Premises Upgraded (£)	297	352

3.6.4 Results by Devolved Administration

The table below provides estimates of the effects of the programme by Devolved Administration. It should be noted that delivery started later in Scotland (with no meaningful delivery until 2014), and later still in Northern Ireland (with delivery commencing in 2015). As such, the results set out below are not estimated over a consistent period and are not strictly comparable. Results are not available for Wales because a Speed and Coverage Template was not available.

Table 3.8: Estimated Effect on Percentage of Premises with NGA and Superfast Availability by Devolved Administration

	PSM (Effect of programme on % of premises with superfast availability on postcodes within the build plans of local schemes)	Fixed Effects (Estimated increase in premises passed by NGA per premises upgraded)
England (effect over 4 years)	30.4	0.53
Scotland (effect over 3 years	21.7	0.60
Northern Ireland (effect over 2 years)	17.5	0.40

4 Conclusions

- Impact: The evaluation results indicate that the Superfast Broadband programme had a substantial effect in extending superfast broadband connectivity to areas that would have otherwise received coverage. It is estimated that by 2016, around 2.25m premises received NGA coverage that would not have done so at all, while a further 1m received NGA coverage two years earlier than they would otherwise have. The evaluation suggests that effects on access to 30Mbit/s connections were larger still, with around 2.5m premises estimated to have gained access to these speeds who would not have otherwise done by 2016 without the programme.

- Open Market Review process: The results of the evaluation suggest that the Open Market Review was largely effective in encouraging providers to reveal their short term commercial plans to enable public funds to be targeted at postcodes least likely to benefit from enhanced connectivity. The findings suggest that those postcodes included within the scope of local schemes were likely to be the least commercially attractive to upgrade to superfast speeds – being largely rural in character and sharing a range of common features that would increase the cost of installation, e.g. higher than average presence of exchange only lines. Additionally, the results suggested high rates of additionality in the short term – it is estimated that over 70 percent of the premises upgraded would not have been installed within two years of delivery without a subsidy.

- Take-up: Take up of superfast broadband services on subsidised connections has proven higher than initially expected – with average take-up of Phase One schemes nearing 40 percent by the end of 2016/17. The results of the evaluation indicate that the programme has led to an increase in average download speeds of 3.2-5.5 Mbit/s on postcodes included in local schemes. Costs have also been lower than expected, and this may have encouraged providers to expand their commercial plans as time passed. This likely explains the apparent reduction in additionality from the second-year post-installation, implying that other areas have started to catch up.

- Crowding out: The evaluation indicates that the programme largely avoided the risk of crowding out private sector investment in areas that were not eligible for the programme (while an effect was found, it was trivial in magnitude). This may be attributable to the timing of the programme. Peak volumes of premises upgraded were delivered in 2015, as levels of activity to upgrade broadband connections in ineligible areas began to fall. As such, it is likely that providers and their supply chains were carrying sufficient capacity at the time to deliver the programme without diverting resources from parallel programmes of investment. The programme was also delivered with a cost of delaying the extension of coverage to a group of premises that would have otherwise received superfast connections approximately one year earlier (likely caused by the time absorbed by the Open Market Review, consultation, tendering and contracting processes).

- Gain-share: The contracts developed to procure the programme has offered the public sector the opportunity to share in the upside associated with higher than expected take-up of subsidised coverage. The gain-share clauses are expected to result in £489m being returned to the public sector (of which £84m was reinvested), offering substantial protections to the value for money associated with the programme. These contractual mechanisms contained the net cost to the public sector per additional premises connected to £352 - which could have otherwise risen to £494 per additional connection, though it is unclear how providers may have otherwise have behaved had the gain-share clauses not been present in the original contract.

- Policy learning: The types of mechanisms referred to above are rarely employed in public sector programmes[36] involving financial support to the private sector and could have more widespread applicability (one example of analogous mechanisms includes the sales contingent loans offered to large aerospace producers through Repayable Launch Investment. It is possible to speculate as to the underlying success factors – for example, it was possible to monitor take-up with accuracy over time, enabling enforceable conditions to be written into contracts, something that may not be feasible when subsidising early stage industrial R&D, where it may be less straightforward to connect the intellectual property developed to any later resultant sales. However, further process evaluation research could be beneficial in understanding any key lessons learned from the process and improving transferability to other areas of Government policy.

[36] One example of analogous mechanisms includes the sales contingent loans offered to large aerospace producers through Repayable Launch Investment.

Appendix: Statistical Tables

Table: A.1: Probit Models

Variable	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
Treatment Group	Phase One & Two		Phase One & Two		Phase One Only		Phase Two Only		Rural Only		Urban Only	
Comparison Group	All other postcodes		White Only		White Only		White Only		White Only		White Only	
Observations in treatment group	234,299		330,308		277,950		42,598		160,617		73,682	
Observations in control group	867,823		61,469		61,469		67,271		19,869		16,419	
Pseudo R-squared	0.49		0.16		0.21		0.16		0.20		0.17	
Variable	Coef.	P>z	Coef.	P>z	Coef.	P>z	Coef.	P>z	Coef.	P>z	Coef.	P>z
NGA access in 2012	-0.24	0.00	-0.31	0.00	-0.33	0.00	-0.12	0.00	-0.28	0.00	-0.29	0.00
NGA access in 2013	-0.75	0.00	-0.49	0.00	-0.61	0.00	-0.08	0.00	-0.69	0.00	-0.39	0.00
% of postcodes in LA with NGA, 13	0.07	0.00	-0.09	0.00	-0.22	0.00	0.40	0.00	-0.06	0.00	-0.44	0.00
% of postcodes in LSOA with NGA, 13	-0.56	0.00	-0.55	0.00	-0.57	0.00	-0.42	0.00	-0.42	0.00	-0.59	0.00
Line Length (m)	0.00	0.00	-0.08	0.00	-0.09	0.00	-0.04	0.00	-0.07	0.00	0.00	0.78
Final speed	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.00	0.01	0.00	-0.01	0.03
Premises with EO lines 2013	0.01	0.00	0.00	0.22	0.00	0.02	-0.01	0.00	-0.01	0.00	0.00	0.00
Delivery points at serving exchange	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Delivery points at serving cabinet	0.00	0.00	0.00	0.08	0.00	0.73	0.00	0.01	0.00	0.00	0.00	0.00
Virgin Media availability	-0.29	0.00	0.41	0.00	0.47	0.00	0.89	0.00	0.23	0.00	0.46	0.00
Estimated Upgrade Cost (£)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cost Per Premises Upgraded	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.91	0.00	0.00
Working Age Population	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Population Aged 65 and Over	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46
(Log) Population Density	-0.42	0.00	-0.16	0.00	-0.16	0.00	-0.23	0.00	0.17	0.25	-0.16	0.00
(Log) Premises Density	0.33	0.00	0.31	0.00	0.33	0.00	0.34	0.00	-0.02	0.00	0.23	0.00
Gross Weekly Wages (in LA)	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00
Employment Rate (in LA)	0.02	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.00	0.00	0.60
Unemployment Rate (in LA)	0.00	0.20	0.00	0.31	0.01	0.00	0.04	0.00	0.01	0.00	-0.02	0.00
Average Download Speeds 2014	-	-	-	-	-	-	-0.01	0.00	-	-	-	-
Maximum Download Speeds 2014	-	-	-	-	-	-	0.00	0.15	-	-	-	-
% of premises with Superfast access 2014	-	-	-	-	-	-	-0.01	0.00	-	-	-	-
% of premises with NGA access in 2014	-	-	-	-	-	-	-0.42	0.00	-	-	-	-
Constant	1.50	0.00	1.21	0.00	1.64	0.00	-1.27	0.00	0.59	0.00	3.76	0.00

Table A.2: Overview of Characteristics of Matched Samples

Variable	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
Treatment Group	Phase One & 2		Phase One & 2		Phase One Only		Phase Two Only		Rural Only		Urban Only	
Comparison Group	All untreated postcodes		White Only		White Only		White Only		White Only		White Only	
Mean standardized bias	4.1		3.9		4.0		2.2		5.5		2.7	
Variable	Treated	Control	Treated	Control	Treated	Control	Treated	Control	Treated	Control	Treated	Control
NGA access in 2012	0.14	0.13	0.12	0.12	0.09	0.09	0.21	0.22	0.07	0.07	0.29	0.30
NGA access in 2013	0.18	0.17	0.16	0.16	0.13	0.13	0.29	0.29	0.08	0.09	0.39	0.39
% of postcodes in LA with NGA, 13	0.52	0.51	0.48	0.51	0.46	0.48	0.60	0.61	0.42	0.46	0.64	0.65
% of postcodes in LSOA with NGA, 13	0.26	0.25	0.25	0.26	0.21	0.23	0.38	0.39	0.12	0.13	0.56	0.55
Line Length (m) / Log Line Length	2591	2678	7.5	7.4	7.5	7.4	7.6	7.6	7.5	7.3	7.2	7.2
Final speed / Log Line Length	9413	9535	7.6	7.6	7.6	7.5	7.4	7.5	7.3	7.1	9.2	9.3
Premises with EO lines 2013	3.6	3.4	2.8	2.7	2.8	2.8	2.80	2.69	3.2	2.8	4.5	4.5
Delivery points at serving exchange	6611	7524	6447	7266	5879	6734	8366	8802	3040	3518	14,397	14,920
Delivery points at serving cabinet	244	239	234	227	239	233	223	216	257	255	216	214
Virgin Media availability	0.06	0.06	0.04	0.04	0.04	0.03	0.08	0.08	0.01	0.01	0.16	0.19
Estimated Upgrade Cost (£)	65,866	66,701	65,612	66,988	66,574	68,718	64,040	62,629	68,160	71,869	60,736	57,224
Cost Per Premises Upgraded	298	323	328.0	360	315	353	374	394	291	363	319	363
Working Age Population	182	183	184	188	178	179	210	214	181	184	186	186
Population Aged 65 and Above	57	55	57	55	57	54	60	60	61	59	48	47
Population Density (log)	6.01	5.92	5.7	5.7	5.7	5.8	5.5	5.5	5.3	5.3	7.5	7.4
Premises Density (log)	5.49	5.43	5.2	5.2	5.2	5.3	4.9	5.0	4.8	4.7	7.1	7.1
Gross Weekly Wages (in LA)	511.1	512.9	510.6	511.4	510.6	511.3	512.0	514.8	514.7	520.6	503.1	503.3
Employment Rate (in LA)	73.3	72.8	73.3	73.0	73.5	73.1	72.7	72.7	74.1	74.0	71.4	71.6
Unemployment Rate (in LA)	6.9	7.1	6.9	7.0	6.7	6.8	7.4	7.4	6.4	6.5	8.0	7.8
Average Download Speeds 2014	-	-	-	-	-	-	9.7	9.6	-	-	-	-
Maximum Download Speeds 2014	-	-	-	-	-	-	20.9	20.8	-	-	-	-
% of premises with Superfast access 2014	-	-	-	-	-	-	13.1	12.7	-	-	-	-
% of premises with NGA access in 2014	-	-	-	-	-	-	0.26	0.26	-	-	-	-

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