SIMETRICA

# Subjective wellbeing analysis of the Superfast Broadband programme

# Annex C

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# 1 Research Objectives and Framework

## 1.1 Introduction

This is the third technical paper in the superfast broadband evaluation annexes, complementing the work carried out on reducing the digital divide and economic impacts of the programme. The findings form part of the overall assessment of the benefits and costs of the BDUK superfast programme as part of the first externally commissioned evaluation of the programme.

The research[1] in this paper involves the derivation of estimates of the impact of superfast broadband on individual subjective wellbeing. The wellbeing impact has occurred over and above any benefits measured in the connectivity and economic impacts evaluation papers (technical annexes A and B).

The focus is on people who live in areas eligible for BDUK funding under the Superfast Broadband programme. The wellbeing impact is valued in monetary terms and forms part of the overall assessment of the cost and benefits of the BDUK scheme[2].

The findings have been developed using a comprehensive, robust means of monetising the value of consumer welfare benefits, based on changes in subjective wellbeing that have arisen post-intervention. The methods used have found increasing support and acceptance in recent years, as evidenced by academic and government publications[3].

The use of subjective wellbeing (SWB) to measure and value impact in the telecommunications industry reflects the increasing importance of this approach in policy-making and business more generally, examples of which include:

- The establishment of the UK National Wellbeing Programme in 2010.[4]
- Endorsement of SWB approaches in HM Treasury's Green Book guidance on cost-benefit analysis (HM Treasury 2018) and use of these techniques in various valuation studies in the UK. [5][6]
- The central role that SWB occupies in OECD wellbeing metrics and guidelines[7]

[1] This work contains statistical data from ONS which is Crown Copyright. The use of the ONS statistical data in this work does not imply the endorsement of the ONS in relation to the interpretation or analysis of the statistical data. This work uses research datasets which may not reproduce National Statistics aggregates.
[2] Wellbeing valuation is endorsed in HM Treasury's revised Green Book guidance (2018), as a potentially suitable method of analysing the social benefits of a policy programme.
[3] Further, the analysis is presented in a manner that is suited to its inclusion in updates to the BDUK benefits model, used by BDUK for impact assessments and business cases.
[4] https://www.gov.uk/government/collections/national-wellbeing
[5] https://www.gov.uk/government/publications/valuation-techniques-for-social-cost-benefit-analysis
[6] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/372165/11-Quality_of_life--quality-of-life-assessment.pdf
[7] http://www.oecd.org/statistics/oecd-guidelines-on-measuring-subjective-well-being-9789264191655-en.htm

- Trends elsewhere in the world towards greater usage of SWB, such as usage of the wellbeing valuation method by governments in Australia[8] and New Zealand[9].

## 1.2 Aims and objectives

The objectives of this research are to assess the impact of superfast broadband on individual subjective wellbeing (SWB), focusing on people who live in areas eligible for BDUK funding under the Superfast Broadband programme, and to value this impact in monetary terms[10].

This is achieved using BDUK rollout data for the Programme and connection speeds at a postcode level, combined with two nationally representative UK household surveys which include people's assessment of their subjective wellbeing. By analysing individuals rather than businesses and controlling for income/earnings in the wellbeing regressions, this study seeks to measure the wellbeing impact of superfast broadband *over and above* benefits measured in the economic impacts analysis.

We discuss the use of SWB measures to value impact in more detail in sections 1.4 and 1.5 below.

## 1.3 Theory of Change

This research complements the other strands of the evaluation which explore the economic impacts and public value of superfast broadband, as part of the first externally commissioned evaluation of the programme. By analysing individuals rather than businesses, the research seeks to measure the wellbeing impact of superfast broadband over and above benefits measured in the economic impacts analysis. It is vital to understand the impact of the policy on individuals and consumers, as the main focus of the programme was to deliver superfast broadband to residential properties.

The initial theory of change prepared for the evaluation indicates that there are many channels through which Superfast Broadband may influence levels of subjective wellbeing, in both a positive and negative direction. For instance, access to the technology may offer benefits in terms of increasing the range of entertainment options available to households, but also may also facilitate rises in internet addiction. As a result, it was necessary to provide quantitative evidence which shed light on the theory of change to understand the extent of impacts realised to date.

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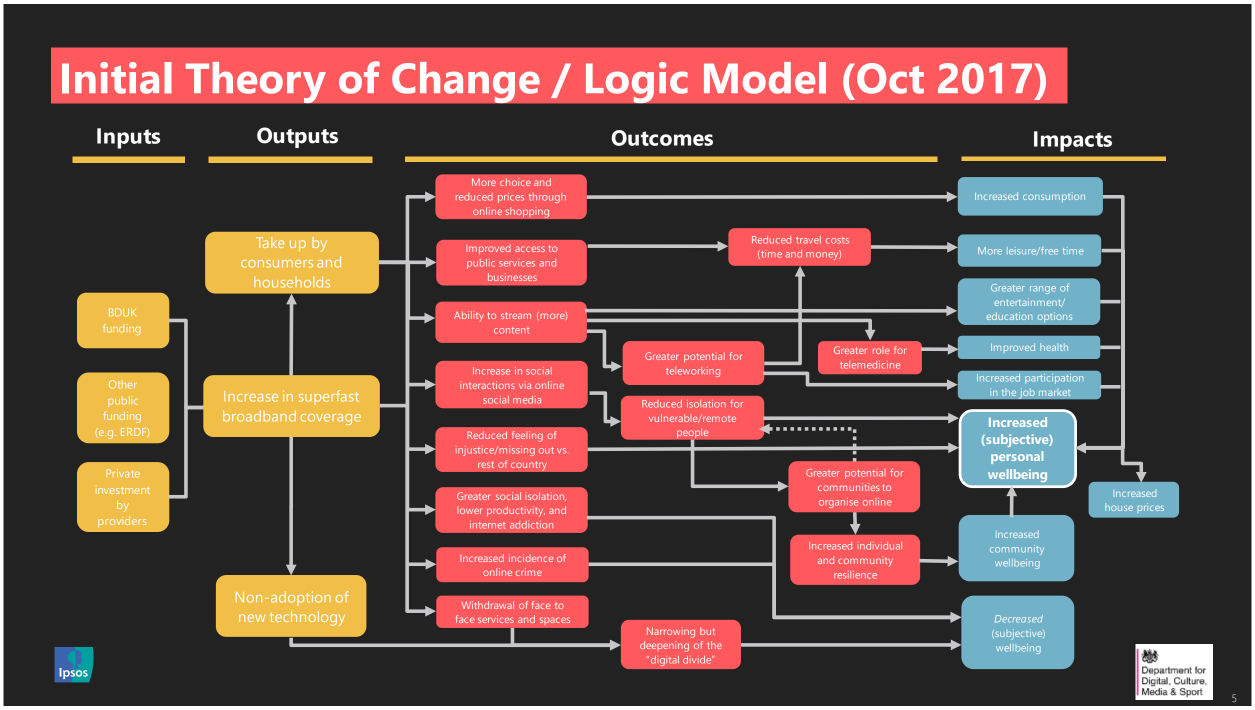
[8] http://arp.nsw.gov.au/sites/default/files/TPP17-03_NSW_Government_Guide_to_Cost-Benefit_Analysis_0.pdf
[9] https://asvb.com.au/2017/08/01/new-zealand-treasury-signs-asvb/

[10] The paper presents results based on the analysis of two datasets that have been developed, presented and commented upon following a number of cross-government steering groups over a period of 10 months, in addition to receiving internal and external peer review and QA and the ongoing support and input of BDUK analytical, commercial and delivery staff.

*Figure 1. Initial Theory of Change*




Source: Evaluation of the Economic Impact and Public Value of the Superfast Broadband Programme, Annex D

## 1.4 Economic foundations of wellbeing evaluation

The general valuation literature in microeconomics has become the standard and best-practice approach to valuation (HM Treasury, 2011; OECD, 2013). At the heart of valuation of policy relevant outcomes is the concept of two welfare measures developed by Hicks & Allen (1934):

- **Compensating surplus (CS)** is the amount of money, paid or received, that will leave the individual in their initial welfare position following a change from the status quo. For example, the CS for having a property upgraded to achieve superfast speeds (which presumably increases an individual's overall welfare) is the maximum amount of money that an individual is willing to pay for the upgrade.

- **Equivalent surplus (ES)** is the amount of money, to be paid or received, that will leave the individual in their subsequent welfare position in the absence of a change from the status quo. For example, the ES for having a property upgraded to achieve superfast speeds is the minimum amount of money that an individual would be willing to accept to forego receiving the superfast broadband upgrade at their property.

CS and ES provide separate estimates of total welfare, i.e. the total gains that an individual experiences by acquiring superfast broadband. However, given that people pay bills for broadband access, it is necessary to estimate the associated **consumer surplus**—total welfare less any money spent on access to superfast broadband.

## 1.5 The wellbeing valuation approach

Research in the relatively new area of Happiness Economics has led to the recent development of an approach to estimating CS, ES and consumer surplus—based on people's reported subjective wellbeing (SWB). This approach, referred to as **Wellbeing Valuation (WV)**, estimates a monetary value from the impact of an outcome, good or policy on the SWB of individuals who actually experience these outcomes, goods or policies. The wellbeing impact is converted into a monetary amount by estimating the equivalent amount of extra income they would have to earn to experience the same wellbeing impact as that of the outcome, good or policy.

In the context of this study, the wellbeing evaluation approach (Fujiwara and Campbell 2011; Fujiwara 2013) gauges people's experience of broadband in practice, using life satisfaction measures of wellbeing that have been tested and found to be robust in a large number of published academic and government studies, e.g. Krueger and Schkade (2008); ONS (2012); Kimball & Willis (2006); and Sales and House (1971). Life satisfaction measures have been established as the best-practice measure of overall wellbeing, see e.g. OECD (2013); Fujiwara and Campbell (2011); Diener et al., (1999) and Veenhoven (2007). These metrics are used as part of the UK Government's National Wellbeing measurement programme and have become a standard used in numerous nationally representative household surveys. They are currently a government-endorsed method of valuing non-market goods (HM Treasury 2018).

A key benefit of applying WV to broadband-related outcomes is that we are able to derive values without asking people directly how much they would be hypothetically willing to pay (as in the Stated Preferences[11] method) and without relying on market data which may be limited in its availability (as in the Revealed Preferences[12] method). Instead, wellbeing values are based on how people actually experience an outcome (Fujiwara & Dolan, 2014). This is key in relation to superfast broadband where some people will not have experienced the outcome directly and may struggle to correctly envisage the impact a subsidised scheme might have on their lives.

This study deploys Fujiwara's (2013) approach to calculating the income equivalent of a shift in subjective wellbeing due to another cause[13].

[11] This is a method for valuing non-market goods or outcomes which elicits a value directly from the respondent in a hypothetical scenario: either by describing the good/outcome and asking for a direct value (also known as contingent valuation) or by presenting a series of hypothetical alternative and asking to choose the preferred one (also known as discrete choice modelling).

[12] This is a method for valuing non-market goods or outcomes which analyses the price of other market goods or services affected by the non-market good or outcome in question. This could be e.g. a fall in house prices where pollution is higher, or a decrease in medical expenditure after a ban on smoking.

[13] At its simplest level, the wellbeing value of an outcome such as a superfast broadband upgrade can be derived as: $WV = \beta_1/\beta_2$, where $\beta_1$ is the estimated effect of broadband on wellbeing and $\beta_2$ is the estimated effect of income on wellbeing. However, to overcome issues of endogeneity with the income variable, (Fujiwara, 2013) proposed a three-stage wellbeing

A potential challenge for the WV method is to find a suitable measure of SWB which can be captured accurately and without bias. With this in mind, SWB is usually measured as an 'evaluation' or as an 'experience'. It is said to be measured as an evaluation when people are asked to provide holistic assessments of their lives overall. Life satisfaction is an example of an evaluative measure, and is the main variable used in WV research at the present time, including this evaluation, in addition to social science more generally (Diener, 2000). It has the benefit of providing a wide-ranging reflection of how people feel about their lives. Although SWB can also be measured as experience, whereby emotions are surveyed repeatedly through an individual's instant responses about his/her momentary wellbeing throughout the day, this approach often requires primary data collection and is therefore not the one taken in this part of the study.

Life satisfaction has been extensively used in the academic and government research literatures (Diener et al., 1999; Veenhoven, 2007). Separately, SWB measures, including life satisfaction, have undergone cognitive testing by the Office for National Statistics, prior to the recognition of measures of SWB as national statistics in 2014 (ONS, 2012). There is a variety of evidence to support the argument that overall life satisfaction is a good measure of wellbeing. Some studies have shown that contextual factors such as the weather can adversely influence and bias life satisfaction responses (Eid, Langeheine, & Diener, 2003; Eid et al., 2003; Fujita & Diener, 2005; Pavot & Diener, 1993; Pavot, Diener, Colvin, & Sandvik, 1991). There is a range of evidence that demonstrates there is a strong correlation between wellbeing ratings and a range of outcomes that we would intuitively relate to wellbeing, such as facial expressions (smiling and frowning) that signal certain emotions, or health. Moreover, life satisfaction has a high level of retest reliability[14] (Krueger & Schkade, 2008) which ensures confidence in the stability of the measure in the absence of changes in circumstance or experience. Overall, therefore, life satisfaction can be viewed as a stable measure of wellbeing. To summarise, estimating the impact of a government-subsidised infrastructure upgrade programme like superfast broadband on SWB offers a means of partially evaluating the programme's benefit to society. Self-reported life satisfaction scores in large, representative sample surveys such as the Annual Population Survey (APS) or Understanding Society (USoc) are considered to offer appropriate proxy measures of an individual's SWB.

### 1.6 Data on broadband and internet connectivity

The OfCom Connected Nations data set is used. This dataset is collected by Ofcom from the network providers, aggregated and made publicly available. It covers the years 2012-16 and is expanding in its scope and level of detail each year.

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estimation approach, where a robust causal estimate of the wellbeing effect of income is obtained from a separate data set. The study uses lottery wins as an instrumental variable for income and also applies a log-transformation to income to account for diminishing marginal utility of money.

[14] A high level of retest reliability indicates that the measurement tool in question (life satisfaction) can consistently reproduce the same result in the same situation and population.

The variables of interest are download speed and Next Generation Access (NGA) internet availability, both of which are initially provided at the premises level but have been aggregated to the postcode level. Information is also used from the BDUK C3 quarterly reports on the date of a BDUK-funded upgrade of the first and last cabinet servicing each postcode (where such an upgrade happened).

### 1.7 Structure of the report

The rest of this paper is set out as follows: Section 2 describes the data and statistical methodology used, Section 3 presents the results of the analysis, Section 4 provides an interpretation of the key findings and presents a narrative based on the results, while Section 5 concludes and presents our recommendations for further research.

Alternative models and sensitivity checks are covered in the Annexes, alongside an example of the full regression output used to generate the results demonstrated in Section 3.

# 2 Subjective wellbeing data and methodology

### 2.1 Data

For the purpose of combining subjective wellbeing and broadband/internet connectivity data, two large nationally representative UK household surveys are used. They cover subjective wellbeing and the demographic characteristics (important determinants of wellbeing) that are used as control variables in the analysis.

The first is the Annual Population Survey (APS)[15]. Five waves of the APS are used, spanning from April 2011 to March 2016, which contain 822,625 respondents. The data are pooled cross-sections: individuals are not tracked over time. The location of the respondents' household can be pinned down at the postcode level. The second is the Understanding Society (USoc) dataset[16], where waves 1-6 are used, spanning the years 2009 to 2015.

USoc tracks households and individuals over time, including 292,688 responses across the six waves in total. Geographical identification of households is less precise, with only the Lower Layer Super Output Area (LSOA) available.

The key differences between USoc and the APS are:

- USoc provides the Lower Layer Super Output Area (LSOA) of the respondent as opposed to the postcode.

[15] The APS data is provided by the ONS via the Virtual Microdata Laboratory under secure access (project number 1008415). These data remain under Crown Copyright.

[16] The Understanding Society data is provided by the UK Data Service under Special Licence access under dataset usage number 116026.

- USoc tracks individuals over time, meaning that we can employ longitudinal methods.
- USoc indicates whether individuals are regular internet users.

The broadband/internet connectivity data is also aggregated to the postcode level so that it can be matched to the wellbeing data in the APS. For use with USoc, the data are aggregated at the LSOA level.

As the APS provides a respondent's full postcode area, we added the average connectivity data for the full postcode of each respondent. As USoc only provides a respondent's lower level super output area (LSOA), a much larger geographic span, connectivity data could only be added to this dataset at the aggregate LSOA level.

Data from the APS is merged with data on broadband and internet connectivity based on the postcode address and the date of the respondent's interview and the date of the cabinet upgrade. Figure 2 sets out the outcomes of merging these two datasets for the analysis.

*Figure 2. Linking the APS and broadband data*

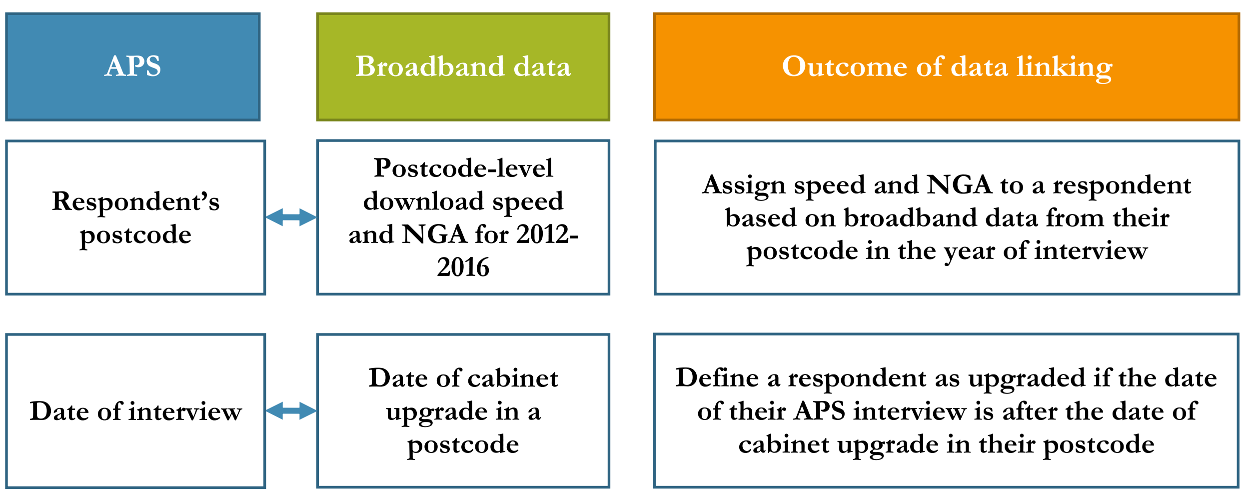
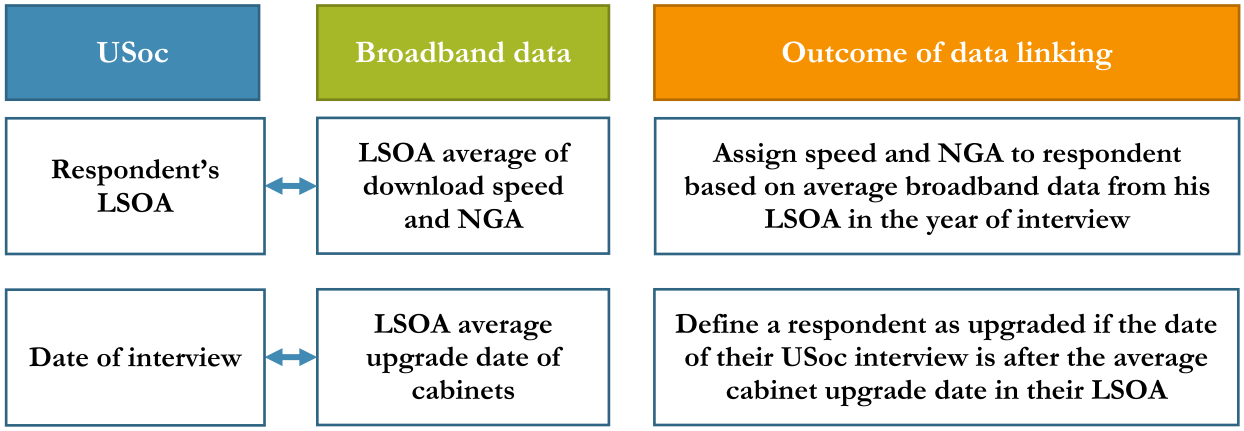


*Figure 3. Linking the USoc and broadband data*




Similarly, data from USoc is merged with data on broadband and internet connectivity based on the respondent's LSOA and interview date and the averaged upgrade date, download speed and NGA of the cabinets (see Figure 3 above).

## 2.2 Methodology

The relationship between life satisfaction (our wellbeing marker) and the programme was estimated using regression analysis. Three alternative measures of life satisfaction (happiness, anxiety and worthwhile life) were utilised to allow cross-checking of results.

Three Superfast Broadband programme related variables were employed in our modelling. These were:

1. Upgrade to superfast broadband—A variable equal to 1 if the cabinet servicing a respondent's full postcode[17] area was upgraded with BDUK funding before the respondent was interviewed, and 0 otherwise[18].

2. Median download speed—median download speed in Mbps of all premises in the respondent's full postcode area in the year of the respondent's interview.

3. Next Generation Access (NGA)—a variable equal to 1 if there was at least one premise in the respondent's full postcode area that attained the speed of a NGA connection (>24 Mbps download speed) in the year of the interview, and 0 otherwise.

[17] Most postcodes are serviced by a single cabinet. If the postcode is split between multiple cabinets, the variable is equal to 1 if the first cabinet was upgraded before the interview.
[18] This is derived from the delivery times of the upgrade works conducted by the bidding network providers and does not derive from actual observed speed at the premises.

In seeking to identify the impact of superfast broadband upgrade in subsidised areas on wellbeing, it is important that the effect of wider factors correlated with upgrade (but not caused by it) which also drive wellbeing are adjusted for[19]. For example, living in a densely populated urban area may affect internet connection speeds (urban households are more likely to be in close proximity to a high speed fibre-connected street cabinet) and may also drive wellbeing in and of itself.

Moreover, it would not be appropriate in estimating the value of superfast broadband to include the additional wellbeing impacts of living in an urban area per se. To help control for these and similar factors we employ a set of statistical models which seek to compare wellbeing for individuals who live in and out of areas with subsidised superfast broadband who are otherwise similar.

After obtaining the regression estimates, they are monetised as described in the footnote in Section 1.5 to produce wellbeing values denominated in sterling.

A key issue for the analysis would be to ensure that we compare upgraded areas to appropriate counterfactual areas which do not differ systematically. For example, it is likely that there are systematic differences between areas upgraded and 'locked out' areas which are ineligible for subsidy. As a result, we adopt two approaches set out in sections 2.2.2 and 2.2.3 which seek to address these issues.

### 2.2.1 Econometric specification

In order to estimate the wellbeing impact of receiving superfast broadband upgrades in subsidised areas, we fit the econometric model below using multivariate ordinary least squares (OLS) regression analysis:

$$SWB_i = \alpha + \gamma Broadband_{\mathrm{i}} + \boldsymbol{X}_i\boldsymbol{\beta} + \varepsilon_i \qquad (1)$$

In equation (1), $SWB_i$ is the outcome variable (an indicator of subjective wellbeing) $Broadband_{\mathrm{i}}$ is the treatment variable (a proxy for variables related to superfast broadband upgrade) and $\boldsymbol{X}_i$ is a set of control variables containing some of the typical determinants of wellbeing. $SWB_i$ (for example, life satisfaction) and $Broadband_{\mathrm{i}}$ (for example, median speeds in the postcode of the respondent) are represented by different variables in different models (one at a time in each model). A list of all relevant outcome, treatment and control variables, is provided in Section 2.2.5 further below. Some controls, such as population density, are taken separately from the National Statistical authorities of England, Scotland, Wales and Northern Ireland.

[19] In econometric terms, this means to ensure that we adjust for any of the observable sources of endogeneity in our estimates of the impact of a superfast broadband upgrade in subsidised areas on subjective wellbeing.

The coefficient $\gamma$ is the key coefficient for our analysis because if it is significant and positive, it would imply that, for example, a cabinet upgrade is associated with an increase in the wellbeing of individuals in areas affected by the upgrade.

In order to theoretically validate our results, it is important to consider issues of endogeneity and measurement error. Descriptive statistics (see Section 3.1) provide evidence that having a higher connection speed or having NGA is correlated with lower wellbeing scores, but this may be largely influenced by third variables such as urbanisation or population density. We seek to mitigate this statistical problem by adopting the pipeline and instrumental variables (IV) approaches detailed below.

Secondly, it is important to note that given that the broadband and internet connectivity data is available at postcode level (or, in the case of Understanding Society data, the data is averaged at the LSOA level), it does not pertain to the respondent's household itself.

While the $Broadband_i$ variable in our data will indicate the speed that can normally be attained in the neighbourhood, it could be the case that the respondent either: does not have a subscription package that allows them to experience such speeds; uses the internet only rarely or not at all; or experiences idiosyncratic technical problems.

Furthermore, the respondent's house may not have access to the same technology as other premises in the LSOA. These issues with geographic aggregation of the broadband and internet connectivity data may cause attenuation bias[20] and make a relationship more difficult to detect. The issue is addressed in a series of sensitivity checks and caveats.

#### *2.2.2 Pipeline design*

We adopt the pipeline design to ensure that the respondents that are coded as receiving subsided superfast broadband live in comparable areas. The essence of this approach is that we restrict the analysis to households who live in areas that have received a BDUK-funded upgrade at some point in time. This is key in ensuring that we address issues around endogeneity such as omitted variable bias or reverse causality, as the timing of the roll-out of broadband is to a certain extent randomised amongst areas. However, this assumption of randomness may not fully hold as there may be systematic reasons determining the timing of upgrade such as the level of wealth in an area. As a result, we also adjust for the key drivers of wellbeing as discussed in section 2.2.5.3.

When we analyse the effects of the upgrade, we consider the households whose postcode/LSOA was upgraded before they were interviewed in the APS/USoc as treated, and those whose postcode/LSOA was upgraded after the interview as controls. The latter will not have experienced the impacts of

[20] A situation when a parameter measured in an econometric model is expected to be smaller in magnitude than the true value of the parameter. In the econometric literature this is a well-known consequence of measurement error in the treatment variable.

superfast broadband at the time their subjective wellbeing was elicited, but nonetheless they live in areas which are more comparable to the former, as both groups were targeted by BDUK funding.

### *2.2.3 Instrumental variables (IV)*

The IV approach consists of finding a source of exogenous variation in the treatment variables—that is another variable or set of variables which changes the likelihood of receiving treatment but does not depend on the omitted factors that might cause a change in the outcome (known as the exclusion restriction). For instance, researchers seeking to understand the impact of income on life satisfaction may use lottery winnings as an instrument for income, as winnings are randomly allocated amongst lottery players after adjusting for the amount that players spend on lottery tickets.

In other words, an instrumental variable will be correlated with the treatment variable but will be uncorrelated with anything else that might cause a change in the outcome variable. Our proposed instruments, informed by the BDUK scoping study of the superfast broadband evaluation and feedback from BDUK, are cabinet size, share of exchange-only lines and distance to cabinet/exchange.

We attempt to exploit the fact that these variables are correlated with superfast broadband availability/speed. Separately, smaller cabinets, higher distances to the cabinet/exchange and exchange-only lines tend to slow down broadband speeds, other factors being equal, and yet they have been determined when the telecommunications network was set up decades ago and so are less reflective of current economic factors or demographics.

Theoretically, while the potential relevance of these instruments is accepted, we cannot guarantee that the exclusion restriction holds, and as a result it is possible that our IV estimates reflect the impact of broadband *and* the impact of other factors. Practically, the exclusion restriction is tested using Sargan's test, while relevance is tested via an F-test in a first-stage regression of the treatment variable on the instrument and other exogenous controls. The predicted treatment from the first stage regression is then substituted as the treatment variable in the second stage regression, if statistically validated.

**As the proposed instruments were found to be inconsistent with the statistical assumptions required for the IV approach to be employed, we present and discuss the results in Appendix 6.**

### *2.2.4 Disaggregated analysis*

An important aspect to shed light on is whether the association between the BDUK superfast broadband upgrade and people's wellbeing varies according to age group, country in the UK, frequency of internet use (USoc only), and rural/urban classification (APS only).

- It is expected that **young people** will benefit more from broadband as they are more active internet users.
- Whether the impacts vary based on **urban/ rural status (based on the Defra definition of rural Output Areas in 2011[21])** is also of interest.
- Furthermore, given that the USoc data contains information on each respondent's **frequency of internet use**, how impacts vary based on regularity of internet use can be considered. It is natural to expect that superfast broadband is much more highly associated with wellbeing for those that do use the internet regularly.

There are two main ways of obtaining disaggregated impact estimates. The first involves splitting the full sample into subsamples of respondents by each category (age, frequency of internet use etc.). The second is to include interaction terms—essentially new variables equal to the product of the treatment variable and an indicator variable for each disaggregation category e.g. age (<=35, 36-64 and 65+). Interaction terms provide an estimation of three separate coefficients in one regression, for the impact of broadband in each age category. The use of interaction terms is favoured for the following reasons:

1. The approach is more parsimonious in terms of model parameter specification, avoiding unnecessary parameters (as the split sample approach allows the coefficients on each of the control variables to vary by disaggregated group).
2. It allows us to conduct statistical hypothesis testing of the differences between the coefficients for various age categories.
3. It is run on the full sample rather than a smaller subsample, thus reducing estimator variance.

For the purpose of comparison, the split-sample estimation results are available in the appendices.

### *2.2.5 Description of variables*

#### 2.2.5.1 Outcome variables

The APS provides several subjective wellbeing (SWB) measures which are used as outcome variables in our analysis (only life satisfaction is present in USoc):

- **Life satisfaction** ("Overall how satisfied are you with your life these days?")
- **Happiness** ("Overall how happy did you feel yesterday?")
- **Anxiety** ("Overall how anxious did you feel yesterday?")
- **Sense of worthwhile** ("Overall, to what extent do you feel the things you do in your life are worthwhile?")

[21] https://www.gov.uk/government/collections/rural-urban-classification

All responses form the core four wellbeing measures in the UK as part of the National Wellbeing Programme. They are measured on a scale of 0-10 in the APS and on a scale of 1-7 in USoc. Therefore, to make the coefficients comparable, we rescale the coefficients from the USoc regressions to map them to the scales used in the APS.

The primary measure in this study is life satisfaction; being an evaluative measure, it offers a broad assessment of overall quality of life and has a large body of supporting evidence in terms of its validity and rigour (Donovan & Halpern, 2002; Waldron, 2010) (for more information on this see Section 1.5). The other SWB measures are used to corroborate and support the life satisfaction results.

#### 2.2.5.2 Treatment variables

The three main treatment variables used throughout the analysis of the APS and USoc are defined in Table 1 as follows:

Table 1. Description of treatment variables linked to APS and USoc

| Treatment variable | APS | USoc |
|---|---|---|
| **Upgraded** | A binary indicator equal to 1 if the cabinet servicing the respondent's postcode[22] was upgraded before the respondent was interviewed, and 0 otherwise. **This is our key variable for analysis within the subjective wellbeing data as it is the only indicator that gives a direct measure of the impact of the policy. Furthermore, we have the exact date of the cabinet upgrade which can be compared to the interview response date[23].** | The upgrade dates of the first cabinet in each postcode are averaged at an LSOA level. The respondent's interview date is compared to this LSOA-averaged upgrade date, with *upgraded* set to 1 if the interview was after the upgrade, and to 0 if the interview was before the average upgrade date. |
| **Median speed** | The median download speed in Mbps of all premises in the respondent's postcode in the year of the interview. | The median download speed in Mbps in each postcode in the year of interview is averaged for all the postcodes in the respondent's LSOA. |
| **NGA** | A binary indicator equal to 1 if there is **at least one premise in the postcode that has a next generation internet connection** (based on Ofcom's definition of >24 Mbps download speed) in the year of the interview, and 0 otherwise. | The binary variable that indicates whether there is **at least one premise in the postcode that has a next generation internet connection** (>24 Mbps) in the year of the interview is averaged across the postcodes in the respondent's LSOA[24]. |

[22] Most postcodes are serviced by a single cabinet. If the postcode is split between multiple cabinets, the variable is equal to 1 if the first cabinet was upgraded before the interview.

[23] There is a notable amount of measurement error along the time dimension in the other treatment variables, as they are measured on a calendar year basis.

[24] The result is therefore the share of postcodes in the LSOA with at least one NGA connection. It is continuous on the [0;1] interval.

#### 2.2.5.3 Control variables

In our models, we control for a wide range of factors which are known to be associated with SWB and health in the vector $\boldsymbol{X}_i$. These are based on the control variables recommended in Fujiwara & Campbell (2011). Some further variables deemed particularly relevant to the spread of broadband are also included:

- Earnings (APS for employed only) / Household income (USoc)
- Age, age squared
- Gender
- Marital status
- Number of children
- Ethnicity
- Educational status
- Employment status
- Religion
- House ownership
- Urbanisation
- Population density
- Region
- Wave of survey
- Month of interview
- Claiming benefits
- Smoking
- Survey mode

We provide reasons for the inclusion of each control variable in the model in Appendix 8.

# 3 Results

## 3.1 Descriptive statistics

Table 2 presents an overview of broadband related variables and wellbeing of the APS/USoc respondents. The statistics are unsurprising—they confirm that the target areas of BDUK funding (the white areas) had the lowest speed to begin with, hence were most in need of improvement. They also confirm that those that received the subsidised upgrade had higher speeds afterwards, compared to those who lived in target areas that have not received the upgrade yet.

The wellbeing summary statistics show that people who live in areas with higher download speeds, on average, have lower life satisfaction. Indeed, this applies whether we consider black (supplied or with potential to be supplied by more than one commercial broadband provider), grey (with exactly one supplier), and white areas (with no planned commercial delivery[25]), or areas with NGA in general compared to those without access. On the other hand, we find that areas which have already received BDUK funding (upgraded) have higher levels of life satisfaction when compared to those that are scheduled to receive funding but have not yet received it (not upgraded).

Table 2. Broadband availability and BDUK intervention status

| | APS | | | | USoc | | | |
|---|---|---|---|---|---|---|---|---|
| **Eligible for BDUK upgrade** | **N** | **Percent** | **av. life sat.** | **av. DL speed (Mbps)** | **N** | **Percent** | **av. life sat.** | **av. DL speed (Mbps)** |
| Black | 596,903 | 74% | 7.47 | 17.39 | 206,243 | 71% | 5.12 | 15.6 |
| Grey | 101,892 | 13% | 7.55 | 14.28 | 34,267 | 12% | 5.2 | 12.55 |
| White | 107,926 | 13% | 7.75 | 9.62 | 51,962 | 18% | 5.28 | 9.95 |
| Total | 806,721 | 100% | | | 292,472 | 100% | | |
| **NGA at interview** | | | | | | | | |
| No | 168,975 | 25% | 7.63 | 8.68 | 35,370 | 22% | 5.15 | 8.63 |
| Yes | 520,141 | 76% | 7.51 | 18.29 | 122,890 | 78% | 5.1 | 15.87 |
| Total with data available | 689,116 | 100% | | | 158,260 | 100% | | |
| **Received BDUK upgrade** | | | | | | | | |
| After interview **(not upgraded)** | 134,774 | 79% | 7.65 | 9.15 | 122,539 | 94% | 5.21 | 11.38 |
| Before interview **(upgraded)** | 35,409 | 21% | 7.73 | 13.88 | 7,491 | 6% | 5.31 | 16.93 |
| Total received upgrade | 170,183 | 100% | | | 130,030 | 100% | | |

Table note. av. life sat refers to average life satisfaction; av. DL speed (Mbps) refers to average download speed in Mbps; life satisfaction is measured on a 0-10 scale in APS and a 1-7 scale in USoc. Data source: ONS.

The negative correlation between life satisfaction and speed and Mean NGA, is confirmed in Table 3. However, the pattern in the USoc data is slightly different from the one in the APS. Whereas the APS pattern shows a negative tendency (respondents with higher levels of life satisfaction have lower

[25] The black/grey/white classification is according to open market review at the beginning of the superfast phases.

speed), in the USoc data, the respondents with life satisfaction lying in the middle of the scale tend to have the best internet connectivity.

The negative correlation between broadband speed and wellbeing most likely captures the confounding effect of living in urban or densely-populated areas, as the data tells us that rural residents have higher wellbeing (and also worse internet connections). That is why it is crucial to employ robust econometric methods that can account for this confounding effect to the best extent possible, as described in Section 2.2.

Table 3. Wellbeing and internet connectivity data

| **Life Satisfaction** | **Number of responses** | **Percentage of total responses** | **Mean download speed** | **Mean NGA** |
|---|---|---|---|---|
| **APS** | | | | |
| 0 | 6,587 | 0.8% | 16.21 | 79% |
| 1 | 3,056 | 0.4% | 16.23 | 78% |
| 2 | 7,333 | 0.9% | 16 | 78% |
| 3 | 11,249 | 1% | 16 | 77% |
| 4 | 18,141 | 2% | 15.98 | 78% |
| 5 | 68,201 | 8% | 15.89 | 77% |
| 6 | 62,007 | 8% | 16 | 77% |
| 7 | 146,729 | 18% | 16.17 | 77% |
| 8 | 257,324 | 32% | 16.04 | 75% |
| 9 | 112,951 | 14% | 15.83 | 74% |
| 10 | 111,878 | 14% | 15.75 | 74% |
| **Total** | **805,456** | **100%** | | |
| **USoc** | | | | |
| 1 | 6,056 | 3% | 13.64 | 72% |
| 2 | 13,381 | 6% | 13.88 | 73% |
| 3 | 18,885 | 8% | 14.15 | 74% |
| 4 | 22,267 | 9% | 14.2 | 74% |
| 5 | 41,221 | 18% | 14.16 | 74% |
| 6 | 105,761 | 45% | 13.96 | 72% |
| 7 | 27,823 | 12% | 13.88 | 71% |

| Total | 235,394 | 100% | | |
|---|---|---|---|---|

Table note. Data source: ONS.

## 3.2 Subjective Wellbeing regression results

This section presents the outputs of the econometric analysis described in Section 2. The pipeline results from the APS are presented first, the main figures from which form the basis of subsequent monetisation. The USoc results are then presented and comparable analysis conducted using treatment defined at the LSOA level. The association with broadband upgrade and speeds of other wellbeing measures are then provided, for the purpose of triangulation. We follow up with a discussion of the key findings, implications and caveats from these results in section 4.

### *3.2.1 Pipeline results*

#### 3.2.1.1 Results from the APS

Table 4 sets out the pipeline results analysed for Great Britain[26]. A small negative and significant correlation is found between median speed and NGA on life satisfaction in areas that are eligible for BDUK funding. The size of these coefficients implies the following:

- Living at a postcode serviced by an upgraded cabinet is associated with a lower life satisfaction score of -0.005 units on the 0-10 scale. **This finding is not statistically significant at the 10% level.**
- A one-unit increase in the median speed (equivalent to an additional 1 Mbps per second) available in a postcode is associated with a lower life satisfaction score of 0.0013 units on the 0-10 scale.
- Living at a postcode where at least one household has NGA is associated with a lower life satisfaction score of -0.024 units on the 0-10 scale.

Table 4: Pipeline model full sample—APS, Great Britain (Wales, Scotland and England)

| Treatment variable | Full model |
|---|---|
| Upgraded | -0.005 (0.731) |
| Median speed | -0.0013* (0.028) |
| NGA | -0.024* (0.065) |

Table note. Beta coefficients presented with p values in parenthesis; excluding Northern Ireland as this does not have postcodes available within the APS; Standard Controls used; OLS regression conducted with heteroscedasticity-robust standard errors as is best practice in SWB analysis; a * indicates statistical significance at the 10% level; a statistical

[26] Although the APS has data on respondents from Northern Ireland, the version of the data that we used in the VML did not have postcodes for respondents in Northern Ireland.

significance threshold of 10% is used, as it is the typical threshold accepted for SWB analysis. Life satisfaction on a 0-10 scale. Data source: ONS.

###### 3.2.1.1.1 Disaggregated analysis

As a next step, a model was run which (disaggregating the GB-wide sample) aimed to identify differential impacts by age group (aged 35 and below, aged 36-64 and 65+). This was achieved by replacing the standard treatment variable with interaction terms of the treatment variable with each of the age categories, as discussed in Section 2.2.4. The results are presented in Table 5[27].

Table 5: Pipeline model coefficients by age—APS, Great Britain (Wales, Scotland and England)

| Treatment Variable | Full model | Aged 35 and below | Aged 36-64 | Aged 65+ |
|---|---|---|---|---|
| Upgraded | -0.005 (0.731) | 0.078* (0.001) | -0.033* (0.048) | 0.001 (0.972) |
| Median speed | -0.0013* (0.028) | 0.0025* (0.048) | -0.0058* (0.000) | 0.0019* (0.007) |
| NGA | -0.024* (0.065) | 0.051* (0.022) | -0.060* (0.000) | -0.004 (0.838) |

Table note. Beta coefficients presented with p values in parenthesis; excluding Northern Ireland as this does not have postcode available within the APS; Standard Controls used; OLS regression conducted with heteroscedasticity-robust standard errors as is best practice in SWB analysis; a * indicates statistical significance at the 10% level; a threshold of 10% is used, as it is the typical threshold accepted for SWB analysis. Life satisfaction on a 0-10 scale. Data source: ONS.

These results imply that the youngest age group draw the most benefits from subsidised superfast broadband. This accords with prior expectations that as this generation have lived most or all of their lives in the internet age, they are likely to be more dependent on it in their day-to-day activities. However, the insignificant or negative relationships for older age categories act as a counterbalance, likely resulting in insignificant effects for the full sample in Table 5 above. The full narrative behind these results is considered in Section 4.

The magnitude of the wellbeing coefficient of the 'upgraded' variable on those aged 35 or younger, is approximately comparable to some other coefficients in the model, such as having a child born in the household. The negative coefficient for those aged 36-64 is -0.033, which is comparable to the wellbeing drop associated with moving from age 24 to 25 (based on the widely observed inverted U-shape relationship between life satisfaction and age[28]).

Other disaggregation analysis allowed for separate coefficients for 1) rural and urban respondents; and 2) England, Scotland and Wales, and is provided in Table 6 below.

Table 6: Pipeline model coefficients by rural/urban classification and by country

| Treatment variable | Urban | Rural | England | Wales | Scotland |
|---|---|---|---|---|---|

[27] All the significant coefficients are robust to clustering standard errors at the local authority level.
[28] Blanchflower & Oswald, (2008). 'Is Well-Being U-Shaped over the Life Cycle?'

| | | | | | |
|---|---|---|---|---|---|
| Upgraded | 0.015 (0.437) | -0.017 (0.277) | 0.004 (0.836) | 0.005 (0.829) | -0.049* (0.052) |
| Median speed | -0.0036* (0.001) | -0.0005 (0.349) | -0.0011* (0.089) | -0.0007 (0.544) | -0.0029* (0.044) |
| NGA | -0.022 (0.186) | -0.025 (0.113) | -0.017 (0.277) | 0.001 (0.951) | -0.077* (0.001) |

Table note. Beta coefficients presented with p values in parenthesis; excluding Northern Ireland as this does not have postcode available within the APS; Standard Controls used; OLS regression conducted with heteroscedasticity-robust standard errors as is best practice in SWB analysis; a * indicates statistical significance at the 10% level. Life satisfaction on a 0-10 scale. Data source: ONS.

Urban respondents tend to have a more positive relationship between wellbeing and the BDUK upgrade itself (insignificant at the 10% level), but the data shows a more negative relationship with their connectivity speed than the average respondent in the full sample. Concerning the respondent's country of residence, it is interesting to note that there are negative and significant correlations between all of the broadband treatment variables and wellbeing for Scotland. Table 7 below shows the correlations for rural and urban respondents vary with age. These results imply that the positive relationship with subsidised upgrade availability for the young respondents found in Table 5 is more pronounced in urban areas, whereas the negative relationship between upgrade and the middle-aged group is amplified in rural areas.

Table 7: Pipeline model coefficients by rurality and age

| Treatment variable | Aged 35 and below | Aged 36-64 | Aged 65+ |
|---|---|---|---|
| **Urban** | | | |
| Upgraded | 0.128* (0.000) | -0.004 (0.861) | -0.027 (0.401) |
| Median speed | 0.0019 (0.225) | -0.0065* (0.000) | -0.0022 (0.143) |
| NGA | 0.077* (0.005) | -0.047* (0.024) | -0.048* (0.074) |
| **Rural** | | | |
| Upgraded | 0.030 (0.349) | -0.051* (0.009) | 0.016 (0.496) |
| Median speed | 0.0027* (0.098) | -0.0058* (0.000) | 0.0029 (0.003) |
| NGA | 0.016 (0.613) | -0.071* (0.000) | 0.028 (0.216) |

Table note. Beta coefficients presented with p values in parenthesis; excluding Northern Ireland as this does not have postcode available within the APS; Standard Controls used; OLS regression conducted with heteroscedasticity-robust standard errors; a * indicates statistical significance at the 10% level; Life satisfaction on a 0-10 scale. Data source: ONS.

#### 3.2.1.2 Understanding Society results

We replicate the analysis performed in the APS using USoc data. In USoc, respondents from all four countries in the UK are geographically identifiable and therefore can be included in the analysis. The results of the baseline full sample model are presented in Table 8 below. Given that life satisfaction is measured on a 1-7 scale in USoc as opposed to a 0-10 scale in the APS, we have performed a linear transformation on the USoc coefficients to map them to the APS scale, for ease of comparison.

Table 8: Pipeline model full sample—all UK

| Treatment variable | Full model |
|---|---|
| Upgraded | 0.111* (0.001) |
| Median speed | 0.0032* (0.058) |
| NGA | 0.031 (0.295) |

Table note. Beta coefficients presented with p values in parenthesis; Standard Controls used; OLS regression conducted with heteroscedasticity-robust standard errors as is best practice in SWB analysis; a * indicates statistical significance at the 10% level; a statistical significance threshold of 10% is used, as it is the typical threshold accepted for SWB analysis. Life satisfaction presented on a 0-10 scale equivalent, rescaled from a 1-7 scale.

These results imply positive wellbeing impacts of upgrade at an LSOA level. The magnitude is, for instance, slightly higher than that of being religious. Speed is also found to have a positive relationship with life satisfaction. The relationship between having access to NGA internet in the LSOA and wellbeing is statistically insignificant.

###### 3.2.1.2.1 Disaggregated analysis

In Table 9 below, we present the results disaggregated by age category (following the same principle as in section 3.2.1.1). Furthermore, we aggregate information on each respondent's frequency of internet use into four categories: those with no access to the internet at work or at home, those who may have access but never use it, infrequent users (who use it less than once a week) and frequent users (who use it several times a week or every day).

Table 9: Pipeline models split by age and frequency of internet use—Understanding Society, all UK

| Treatment variable | Full model | Ages 35 and below | Ages 36-64 | Ages 65+ |
|---|---|---|---|---|
| Upgraded | 0.111* (0.001) | 0.095* (0.097) | 0.109* (0.011) | 0.133* (0.025) |
| Median speed | 0.0032* (0.058) | 0.0072* (0.003) | 0.0020 (0.313) | 0.0017 (0.527) |
| NGA | 0.031 (0.295) | 0.075* (0.091) | 0.003 (0.921) | 0.044 (0.328) |

| Treatment variable | No access to internet | Never use internet | Infrequent users | Frequent users |
|---|---|---|---|---|
| Upgraded | 0.022 (0.903) | -0.035 (0.753) | -0.041 (0.739) | 0.138* (0.000) |
| Median speed | -0.0011 (0.785) | 0.0076* (0.015) | -0.0037 (0.269) | 0.0035* (0.044) |
| NGA | -0.056 (0.477) | 0.108* (0.057) | -0.081 (0.187) | 0.037 (0.231) |

Table note. Beta coefficients presented with p values in parenthesis; Standard Controls used; OLS regression conducted with heteroscedasticity-robust standard errors as is best practice in SWB analysis; a * indicates statistical significance at the

10% level; a statistical significance threshold of 10% is used, as it is the typical threshold accepted for SWB analysis. Life satisfaction on a 1-7 scale.

We find that, contrary to the APS results, the relationship between living in an upgraded area and wellbeing is marginally higher for older respondents. However, speed and NGA still have a stronger positive wellbeing correlation for younger respondents.

The results disaggregated by frequency of use intuitively denote that the wellbeing benefits associated with upgrade are stronger and more significant for those respondents who use the internet frequently (last column). This seems to be the factor that drives the aggregate coefficients as well, as frequent users make up about two thirds of the full sample. Other categories of people who cannot or do not use the internet or use it less frequently, do not for the most part have a significant association between broadband variables and wellbeing, with the exception of results for median speed and NGA for never-users.

#### 3.2.1.3 APS LSOA-level analysis

In order to look further into the differences caused by aggregating at LSOA level as opposed to postcode level, the geographical aggregation used in USoc for the APS data was replicated. This meant replacing the postcode-level broadband data used in the APS with the LSOA-level broadband data aggregates generated for use with USoc. For brevity, this sensitivity analysis is only presented for the 'upgraded' variable. It can be seen in the table below that the estimated coefficients tend to become more positive when switching from postcode-level to LSOA-level aggregation in the APS.

Table 10: Comparison of postcode-level vs. LSOA-level analysis based on upgrade variable

| **Aggregation level** | **Full model** | **Aged 35 and below** | **Aged 36-64** | **Aged 65+** |
|---|---|---|---|---|
| APS - postcode | -0.005 (0.731) | 0.078* (0.001) | -0.033* (0.048) | 0.001 (0.972) |
| APS - LSOA | 0.011 (0.252) | 0.068* (0.000) | -0.022* (0.063) | 0.035* (0.018) |
| USoc - LSOA | 0.111* (0.001) | 0.095* (0.097) | 0.109* (0.011) | 0.133* (0.025) |

Table note. Beta coefficients presented with p values in parenthesis; Standard Controls used; OLS regression conducted with heteroscedasticity-robust standard errors as is best practice in SWB analysis; a * indicates statistical significance at the 10% level; Life satisfaction on a 0-10 scale—rescaling was performed for USoc. Data source: ONS.

Further sensitivity analysis around measurement error around geographical identification of the treatment variable, can be found in Appendix 5.

#### 3.2.1.4 Alternative measures of wellbeing

Further triangulation of the wellbeing impact can be performed by analysing the three other ONS wellbeing outcomes—happiness, anxiety and the sense of a worthwhile life. These measures are only available in the APS. In the table below, we can see that the relationship between these alternative wellbeing measures and the BDUK upgrade is generally more negative than the life satisfaction impacts (note that anxiety is an inverted variable, with higher values indicating lower levels of SWB), with the only exception of worthwhileness for young people, which is more positively correlated than life satisfaction. It is also noteworthy that upgrade is associated with higher anxiety for those aged 65 and over.

Table 11: Pipeline models treatment effect by age - Great Britain (Wales, Scotland and England)

| **Outcome variable** | **Full model** | **Aged 35 and below** | **Aged 36-64** | **Aged 65+** |
|---|---|---|---|---|
| Life satisfaction | -0.005 (0.731) | 0.078* (0.001) | -0.033* (0.048) | 0.001 (0.972) |
| Happiness | -0.031 (0.069) | 0.019 (0.558) | -0.049* (0.017) | -0.026 (0.283) |
| Anxiety | 0.035 (0.130) | 0.016 (0.709) | 0.019 (0.502) | 0.070* (0.035) |
| Worthwhile | -0.013 (0.320) | 0.102* (0.000) | -0.048* (0.002) | -0.012 (0.544) |

Table note. The treatment variable is always the BDUK upgrade before interview ('upgraded'), using the pipeline approach. Beta coefficients presented with p values in parenthesis; excluding Northern Ireland as this does not have postcodes available within the APS; Standard Controls used; OLS regression conducted with heteroscedasticity-robust standard errors as is best practice in SWB analysis; a * indicates statistical significance at the 10% level; All outcome variables on a 0-10 scale. Data source: ONS.

### 3.3 Further sensitivity checks

Further issues, such as split-sample analysis, the persistence of the wellbeing impacts over time (measured by the duration effects model), fixed effects estimation, a comparison of the APS and USoc regression coefficients, and further sensitivity checks around the measurement error are presented in the appendices. The key insights from these analyses are as follows:

- A split-sample approach by age group generally reduces the magnitude and significance of the coefficients, but no unambiguous pattern can be found. The split sample models produce a positive coefficient for those aged 35 and below and a negative value for individuals aged 65 and above in England and Wales (excluding Scotland). Note that section 2.2.4 establishes the interactions approach as preferred to the split-sample approach.

- The main regression outputs from USoc are reasonably robust to a fixed-effects specification and redefinitions of the treatment variable that gauge measurement error.

- The duration effects model highlights that the impacts of the upgrade persist at least a year after the upgrade has occurred (a longer time lag is hard to analyse due to how recent the BDUK funded upgrades are).

### 3.4 Monetisation and aggregation of wellbeing results

The wellbeing associations presented in Section 3.2.1 are monetised using Fujiwara's (2013) three-stage wellbeing valuation approach[29][30][31], described in Section 1.5. By comparing these effects with the wellbeing impact of income, per-person per-year monetary wellbeing estimates for both the BDUK subsidy and an extra Mbps of internet speed are obtained. These are presented in the upper half of Table 12 below.

Wellbeing values per person broken down by age group are used to aggregate impacts over the target population, arriving at the total yearly wellbeing value for the BDUK programme. Given the variation in values between age groups, this approach is statistically better than estimating average value from a single one-size-fits-all model.

The lowest geography level for which a population breakdown could be found for the respective age categories was the LSOA (Data Zone in Scotland). It was therefore possible to calculate the wellbeing value of the programme for each LSOA in the UK[32] using this population breakdown and the values in the table above. The value for each LSOA was then summed to produce a nation-wide value and was then divided by the population / number of premises of all included LSOAs to get a weighted average per person / per premise value.

One aggregation approach is to count all respondents in those LSOAs where at least one postcode was upgraded. The values are presented in the middle rows of Table 12. Another approach is to only count those respondents in the upgraded postcodes. In practice, this is achieved by scaling down the LSOA values by the percentage of upgraded postcodes. These values are in the bottom rows of Table 12. The former values are higher than the latter, as only about 43% of the postcodes were upgraded on average in a treated LSOA.

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[29] The results of this study are based on the relationship between income and wellbeing for a sample of lottery players. Given that an income variable is likely to suffer from endogeneity bias, the clearest exogenous changes in income are likely to come from data on lottery wins from the British Household Panel Survey (BHPS). The study specifically uses previous lottery wins to capture lottery playing preferences, under the assumption that frequent lottery players will tend to win more on average.

[30] In addition to lottery wins, a variety of instruments have been used in the Wellbeing Valuation literature to resolve issues such as endogeneity. These include sight of payslips (Powdthavee, 2010), father's years of education (Knight et al, 2009) and wage differentials by industry (Pischke, 2011). We note that Fujiwara (2013) produces the most reliable estimates given that these alternative instruments are unlikely to be independent of the potential treatment (here income) and life satisfaction. Given that the Fujiwara (2013) income coefficient is relatively higher in magnitude than the other estimates whist still being plausible, it produces the lower valuations of the impact of outcomes on subjective wellbeing and therefore provides more conservative estimates to be used in policy evaluation.

[31] Fujiwara (2013) uses a control function (CF) approach instead of the 2SLS approach that is commonly used in instrumental variables estimation. The CF approach derives estimates of the average partial effect for income, a clear treatment effect for a well-defined sample group. In other words, the approach generates unbiased casual estimates for income for a well-defined general population group. This is also an estimate which has high levels of external validity as a large number of people played the lottery in the UK during the time period over which the analysis was conducted.

[32] For models based on the APS, we extrapolate the findings to Northern Ireland populations to include them in the aggregation, even though the APS analysis excludes Northern Ireland.

Those monetary aggregates where the aggregation method is conceptually inappropriate (in light grey in the table) were discarded. In the model where the upgraded variable is defined by postcode-level data, it makes sense that we only count those postcodes that were upgraded, as the others were not included in our analysis. In the models where the upgraded variable is defined by LSOA-level aggregates, theory suggests attenuation bias due to some untreated respondents being coded as treated. To mitigate that, it makes sense to count all respondents in the treated LSOAs when aggregating.

Table 12: Wellbeing values—per person per year and aggregates

| **Per person wellbeing values by age category** | | | | | |
|---|---|---|---|---|---|
| **Target population** | **APS—BDUK upgrade** | **APS—upgrade at LSOA level** | **USoc—BDUK upgrade** | **APS—speed (per Mbps)** | **USoc—speed (per Mbps)** |
| All adults | -£82.70 | £197.06 | £1,997.31* | -£22.43* | £56.23* |
| Age 16-35 | £1,385.07* | £1,201.90* | £1,699.10* | £43.91* | £125.72* |
| Age 36-64 | -£565.09* | -£385.33* | £1,945.00* | -£100.22* | £34.11 |
| Age 65+ | £12.59 | £616.29* | £2,404.21* | £32.28* | £28.92 |
| **Aggregate annual wellbeing values** | | | | | |
| Count all treated LSOAs | | | | | |
| Per targeted person overall | £126.22 | **£265.37** | £1,652.55 | -£22.65 | £50.59 |
| Per targeted premise overall | £298.64 | **£627.87** | £3,910.01 | -£53.58 | £119.69 |
| Count % of treated postcodes in LSOAs | | | | | |
| Per targeted person overall | **£93.78** | £231.07 | £1,556.16 | -£22.27 | £45.61 |
| Per targeted premise overall | **£222.25** | £546.72 | £3,681.95 | -£52.70 | £107.91 |

Table note. A * indicates statistical significance at the 10% level of the coefficient in the regression.

Values per person and per premise are averages over users *and* non-users in BDUK funded areas, i.e. per targeted person or premise[33].

**The wellbeing values presented in Table 12 can also be interpreted as consumer surplus estimates.** In particular, the monthly value can be compared to the prices charged by operators for broadband. It is important to keep in mind, however, that the wellbeing values represent the surplus over and above the incremental changes in price resulting from the BDUK upgrade. Also, they are average values obtained by aggregating different points on the demand curve: some consumers may

[33] To be used in the BDUK benefits model they must be multiplied by the inverse of the take-up rate of superfast broadband to recover value per person or premise for those who have connected. An adjustment must also be made to remove any increase in speed which would have happened without the subsidy, estimated at 40% of the total increase in the "Reducing the Digital Divide" section of the BDUK evaluation program (technical annex A).

value broadband more and others—less. This variation is likely to also be seen in a qualitative interview study that samples a broad range of population members.

# 4 Discussion and Analysis

## 4.1 Main Findings

The main findings from Table 12 and more generally from the analysis of USoc and the APS are that:

- **Results based on the BDUK upgrade variable are more consistent in terms of sign and magnitude than could be produced from the speed or NGA access variables, where the relationship with wellbeing was found to differ between the datasets, e.g. the value per Mbps of speed per targeted person was £45.61 in USoc and -£22.27 in the APS.**

When using median download speed as the treatment variable, the fact that one dataset (the APS) provides a negative estimate of the wellbeing value of speed and the other dataset (USoc) provides a positive estimate is a sign of the low reliability of using this treatment variable. This type of sign change is not observed for the upgrade models.

The upgrade variable relies on exact cabinet upgrade and interview dates, in contrast to the download speed and NGA, which are calculated from calendar year dates, thereby introducing measurement error which is likely to make results calculated in USoc less precise. For these reasons we set aside the speed and NGA results, and recommend using the upgrade models as the main source for our valuation estimates[34].[35].

We note that the midpoint of the per targeted person estimates for speed comparing USoc and the APS (an average of -£22.27 and £45.61) is comparable with the results calculated using the postcode level upgrade variable in the APS, once these are re-expressed as value per Mbps (£12.06).

- **Estimated impact values based on the upgrade variable were materially higher in USoc than APS, including when adjustment was made for differences in geographical aggregation of the treatment variable and coverage between the two datasets.**

[34] The upgrade variable is also preferable for updating the BDUK model.

[35] Since the BDUK benefits model takes a change in speed as input, obtaining an estimate of the wellbeing value of additional speed by dividing the average per targeted person value by the average speed difference associated with the BDUK programme, estimated by Ipsos Mori as 7.4 Mbps, is recommended. The value can also then be expressed per one per cent increase in speed (a semi-elasticity) based on the estimated relative speed increase associated with the programme: 78%. More precisely, it takes $\log_{1.01}1.78 = 57.95$ increases of 1% to get a 78% increase. We therefore divide the per person value of the upgrade by 57.95 to get a per person per 1% speed increase value.

- **Whilst the USoc findings corroborate the positive headline results from APS, they are not otherwise recommended for use as estimates of impact. Their size (around six-fold greater than in APS) could reflect statistical problems in the analysis of that dataset.**

There are several possible reasons for the difference in results between the two datasets:

The geographical information which USoc provides is much less specific, increasing the risk of estimation error using that dataset: In particular, USoc only provides geographical identifiers at LSOA level for respondents. In theory, this reduces the fit of the model and increases estimator variance, raising the likelihood of results which are not reflective of underlying causal relationships. The results based on the APS are therefore preferred, as they offer greater precision in measurement.

USoc respondents may display an early-adopter value, which could be higher than for the whole group who will be treated by the BDUK programme. The main part of the BDUK rollout occurred in 2014 and 2015. However, the USoc data ends in 2015, a year earlier than the APS. As a result, those who are classified as treated in USoc are likely to be the earliest recipients of the BDUK-subsidised upgrade.

A higher than average valuation is likely for these respondents because of comparative utility effects (people may value their speed partly with reference to what their peers or neighbours have) and habit formation (people may value their speed partly compared to what they had last year). Over time, adaptation is likely to reduce the component of wellbeing impact which is driven by these factors, muting its impact in APS. Similarly, it is likely that those who first chose to take up superfast broadband when it was made available in their areas are those who had the highest valuations for the product, in a way that might not have applied to those who took it up later.

The treated sample in the USoc data is much smaller than in the APS: Only about 6% of the sample in the pipeline design in USoc experienced an upgrade to superfast broadband. Relying on this small subsample of all upgraded units may risk making the resulting estimates imprecise and also susceptible to capturing non-representative effects (e.g. the early adopters effect described above). About 21% of the APS sample in the pipeline design experienced an upgrade, allowing us to place greater confidence in the precision of estimates obtained using this dataset.

There are differences between the life satisfaction measurement scales used in the two datasets: As set out in Section 2.2.5.1, using the APS results is recommended instead.

- **Although there is some evidence that superfast broadband enabled in one postcode may also have benefits in other postcodes in the same LSOA, evidence on this point is not robust and using the values which do not include these spillover effects is therefore recommended.**

- **In particular, a three-fold larger relationship between upgrade and wellbeing was found in the APS when the comparison was between subsidised and non-subsidised LSOAs than between subsidised and non-subsidised postcodes[36]. This difference is likely to reflect statistical problems in the LSOA level analysis, in addition to spillover effects.**

The postcode-level treatment model using the APS data reflects the raw impact of the BDUK programme excluding spillovers, whereas the LSOA-level variant using the APS data may also capture possible spillover effects. This is because, when treatment data is aggregated to LSOA level, someone whose neighbouring postcode was upgraded will also be coded as treated. If there is a wider-area impact, such as an increase in the affluence of neighbouring postcodes due to the BDUK upgrade, the larger treatment areas will better capture this effect.

Although this may explain some of the three-fold difference in the estimates of value between the postcode level and LSOA level models in the APS, it does not explain the entire gap. The difference may also indicate statistical problems in the LSOA-level results. Based on this assessment the results of the (pipeline) APS postcode-level upgrade model are recommended as the basis for the final wellbeing valuations. These results have the added advantage that they rely on a postcode-level broadband variable, rather than on an LSOA level average, which will be less correlated with the broadband connections which individual households actually have.

- **Upgrading to superfast broadband is associated with a wellbeing uplift equivalent to £222.25 per year for the average targeted premise, corresponding to £3.83 per year per targeted premise per 1% increase in broadband speed.**

- **This is the estimated benefit experienced by households on upgrade on average and can be used as an estimate of future impact up until the technology becomes redundant.**

Whilst we control extensively for all relevant determinants of wellbeing that are available in the APS, unobserved factors could conceivably remain which are correlated with upgrade and also drive wellbeing, e.g. personal proactiveness.

Similarly, although our methodology focuses on postcode areas which will receive funding in the end, there could still be unobservable differences between those which received funding sooner and those which received later. For instance, some areas may have been upgraded earlier due to higher quality local council processes, which are also likely to influence wellbeing.

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[36] The latter in effect allocating spillover effects to comparison rather than treatment areas, deducting rather than adding them to the estimate of impact.

A statistically significant association between upgrade and wellbeing therefore cannot be taken as indicating a fully causal effect and we cannot discard the possibility that it also captures the influence of other factors.

Equally, the £46 may be representative of impact for those who had taken up the technology by the time of the survey, but too large for those who will benefit later, as early adopters may differ from the average. Similarly, it could include a bias effect due to household mobility, for example if some households relocated to areas as a result of upgraded broadband there, but already had greater wellbeing before the relocation.

These factors may explain why, arguably, the headline wellbeing value of the upgrade (£46 per premise per month if adjusted by the inverse of the current take-up rate of 40% as estimated in the "Reducing the Digital Divide" working paper)[37] is somewhat larger than the current average cost of superfast broadband (£30-£40 for residential customers for BT Infinity).

An alternative view however is simply that the results indicate considerable value from superfast broadband versus having no broadband at all or a household's existing package, which are not factored into the price of broadband. The reasons for this may include heterogeneity in the value that households place on access (variation by age group is indicative of this) or consumers' inability to anticipate the full benefits they would derive from superfast broadband before they have tried it out[38].

It is plausible that broadband providers may also have had an incentive to offer superfast broadband at low prices early in the roll-out process (increasing consumer surplus in the short term), but that these may not have persisted in the longer term for loyal customers[39]. Similarly, the values may reflect self-employed income benefits and an increase in house prices, which correctly we do not control for, as these are not reflected separately in the BDUK model or in the other models in this evaluation and can therefore be included in the wellbeing estimates.

Overall, it is Simetrica's assessment that the headline values produced are robust for use in the BDUK model, although BDUK may wish to consider a small adjustment to account for the infeasibility of controlling for all determinants of wellbeing which may be correlated with broadband upgrades.

- **The degree of variation in the headline values (per premise per month) between age groups is large and should be considered when using the average valuation.**

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[37] The value is calculated by multiplying the per targeted premise per calendar month value of £222.25 / 12 = £18.52 by 2.5 (inverse of the 40% current take-up rate).
[38] If consumers are unable to fully identify the benefits of superfast broadband before use, they will on average place lower value on it which will cause downwards pressure on demand and prices.
[39] This provides a further explanation for the higher results found in USoc, which covered the period to 2015, than in the APS, which ran to 2016.

The variation may reflect differing levels of interest and preference for connectivity between age groups. For example, as people aged under 35 are the most likely adult group to embrace superfast broadband and use it regularly, it is intuitive that upgrade to superfast broadband should impact positively on them.

On the other hand, there is a consistent negative association between life satisfaction and superfast broadband for middle-aged respondents (aged 36-64), which may reflect lower levels of usage of the technology in this age group (despite paying for their family's connection). It is possible that variation in the results between age categories also reflects unobserved interruption factors which the area-level control variables such as rurality, region or population density could not fully control for.

Temporary disruption effects from introducing new technology may also be relevant in explaining the negative association detected for those aged 36-64. These effects might include adjustment costs of adapting to new technology, which could be felt more keenly by the over 35s than the under 35s. For example, large infrastructure projects that deliver net benefits to the economy or in the end to wellbeing may still be disruptive for some people during the construction phase (e.g. those living nearby).

By analogy, the introduction of superfast broadband may possibly disrupt the 'status quo' in a community and impact adversely on wellbeing in the short-term, but produce positive economic impact alongside this and, in the longer term, positive wellbeing impact too.

A broader statistical issue may also be relevant: it was not possible to control for the prices that respondents pay for broadband as this data is not available to us in a usable form. As a result, the findings only pick up the benefits of subsidised broadband to the extent that customers do not pay for these through higher prices.

This may explain the low values for some age groups. If total value is required, the price differential may be added.

## 4.2 Wider caveats

Whilst it has been advised that the results should not be treated as reflecting a causal effect of the programme alone, they are nonetheless based on best practice methods and, with the adjusted set out above, represent a best possible estimate of this kind from the data available. They have also passed a series of sensitivity checks that probe the extent to which interruption factors may have influenced the findings.

All of the valuation results in this report may be affected by potential measurement error. Whether the available broadband data was aggregated to postcode or LSOA level or not, it did not allow the identification of whether each individual respondent's dwelling had been included in the subsidised superfast infrastructure, added to the superfast network or whether the respondent had then taken up the technology.

Furthermore, in the APS, it was not possible to identify whether a respondent uses the internet frequently. Any differences between individual values and the aggregated data will constitute measurement error. Although attenuation bias was adjusted for in estimating value per targeted person and premise, the overall precision of the estimates could still have suffered.

Adjustments are necessary when aggregating the headline per targeted premise value (£3.83 per year per 1% increase in speed) to estimate the total impact of the BDUK programme. These are listed in detail in Appendix 1.

# 5 Conclusion

## 5.1 Concluding remarks

This paper has involved the estimation the impact of BDUK's Superfast Broadband programme on individual subjective wellbeing, focusing on people who live in areas eligible for BDUK and local government funding. The analysis indicates that access to superfast broadband is associated with an increase in wellbeing, measured as life satisfaction, even when controlling for key determinants of wellbeing and restricting the analysis to areas which had received funding or would receive it eventually.

## 5.2 Suggestions for further research

**To test, corroborate and elaborate on the key results, bespoke data collection is recommended.** Ideally, access to information on the connection speeds experienced by the respondents to a SWB survey would be desirable. This is achievable, for example, by carrying out a bespoke online comprehensive customer satisfaction survey that would gather data on internet use and broadband speed access at an individual level, as well as prices paid for broadband, subjective wellbeing, and questions on the relevant control variables. Such a study design would eradicate most measurement error in the treatment variables, allow earlier and later adopters to be distinguishable, and enable further investigation into the relationships between wellbeing impact and price of broadband. As a result, it would provide additional certainty and accuracy in relation to the impact of the BDUK Superfast Broadband programme.

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# 7 Appendix 1. Recommendations for input into the BDUK model

**Overall, the assessment is that the headline values produced are robust for use in the BDUK model, although one may wish to consider a small adjustment to account for the infeasibility of controlling for all determinants of wellbeing which may be correlated with broadband upgrades.**

Here are the three final steps to be taken to ensure appropriate use of the value in cost-benefit analysis.

- **Accounting for change which would have occurred in the absence of the programme:** In Annex A—Reducing the Digital Divide it is estimated that about 40% of the increase in speed associated with the BDUK programme would have happened even if the programme had not taken place. As a result, only the remaining 60% can be viewed as due to the subsidies provided.
- **Including an adjustment for take-up:** BDUK data shows that less than 40% of households living in upgraded areas have subscribed to a superfast broadband package to date. However, the remaining households were also coded as upgraded in our data (because of the aggregate nature of the Connected Nations data) despite not being expected to have an effect. The estimates are therefore lower than the true impact per premise having taken up the technology and must be scaled by the inverse of the take-up rate of 40%.
- **Reflecting depreciation and discounting:** The initial values provided by wellbeing valuation are yearly. For long term policy analysis, assumptions should be made about the number of years for which value will be felt and at what proportion of the initial quantum. Future values should also be discounted before they are summed.

*Further notes on the different value estimates include:*

- The value per 1% increase in speed was derived using the estimated relative increase in speed due to the BDUK upgrade, estimated at 78% in the "Reducing the Digital Divide" section. It was further assumed that 1% increases are compounded, i.e. it takes $log_{1.01}1.78 \approx 57.95$ increases of 1% to reach the 78% increase cause by the BDUK upgrade. The total effect of the upgrade is therefore divided by 57.95 to get a value of a 1% increase in speed.
- Estimated impact values were materially higher in USoc than APS, including when adjustment was made for differences in geographical aggregation of the treatment variable and coverage between the two datasets. Whilst the USoc findings corroborate the positive headline results from APS, they are not otherwise recommended for use. This is because USoc provides a materially smaller sample than the APS. Particularly, due to the earlier years it covers, USoc contains much fewer households benefiting from superfast broadband.

Impact is therefore harder to assess in that dataset. Also, the geographical information it provides is much less granular, at LSOA level, introducing added uncertainty in the analysis of that dataset. It is therefore likely that the size of our results in USoc (around six-fold greater than in APS) reflects statistical problems in using that dataset to analyse broadband. It may also (due to the earlier years covered in USoc) reflect an early-adopter result which is not representative of value for the average person to be impacted.

- Although there is some evidence that superfast broadband enabled in one postcode may also have benefits in other postcodes in the same LSOA, evidence on this point is not robust and so we recommend updating the BDUK model instead based on the headline value which does not include these spillover effects. In particular, there is a three-fold larger relationship between upgrade and wellbeing in the APS when analysing subsidised and non-subsidised LSOAs than when analysing subsidised and non-subsidised postcodes. Whilst some of this difference may reflect spillover effects captured in the LSOA analysis which are lost in the postcode level regression, the magnitude of the difference is too large to be a spillover effect alone and may also indicate statistical problems in the LSOA-level results. Therefore, it is recommended to use the APS analysis based on the *postcode* upgrade variable.

A finer disaggregation by age of the per person per year wellbeing values is presented in the table below:

Table 13: Wellbeing values of upgrade in own full-postcode area—5 & 10 year age splits

| Age category | Estimated impact on life satisfaction | Wellbeing value |
|---|---|---|
| 16-20 | -0.081 | Not significant (N/S) |
| 21-25 | 0.033 | N/S |
| 26-30 | 0.051 | N/S |
| 31-35 | -0.003 | N/S |
| 36-40 | -0.002 | N/S |
| 41-45 | -0.014 | N/S |
| 46-50 | 0.061* | £1,080.96* |
| 51-55 | 0.033 | N/S |
| 56-60 | 0.048 | N/S |
| 61-65 | -0.016 | N/S |
| 66-70 | -0.039 | N/S |
| 71-75 | -0.070* | -£1,191.83* |
| 76+ | -0.059* | -£1,007.29* |
| | | |
| 16-25 | -0.010 | N/S |
| 26-35 | 0.019 | N/S |
| 36-45 | -0.008 | N/S |
| 46-55 | 0.047* | £820.66* |

| | | |
|---|---|---|
| 56-65 | 0.015 | N/S |
| 66-75 | -0.053* | -£910.04* |
| 76+ | -0.059* | -£1,004.49* |

Table note. a * indicates statistical significance at the 10% level of the coefficient in the regression. Data Source: ONS.

# 8 Appendix 2. Comparison of interaction-term and split-sample models in the APS

The split sample models produce a positive estimate for those aged 35 and below and a negative value for individuals aged 65 and above. Furthermore, a comparison of interaction-term and split-sample models by age groups is provided in Table 14 below.

Table 14: Pipeline treatment effect by age—interaction vs. split sample models (APS)

| Treatment variable | Full model | Ages 35 and below | Ages 36-64 | Ages 65+ |
|---|---|---|---|---|
| **APS—Interaction terms** | | | | |
| Upgraded | -0.005 (0.731) | 0.078* (0.001) | -0.033* (0.048) | 0.001 (0.972) |
| Median speed | -0.0013* (0.028) | 0.0025* (0.048) | -0.0058* (0.000) | 0.0019* (0.007) |
| NGA | -0.024* (0.065) | 0.051* (0.022) | -0.060* (0.000) | -0.004 (0.838) |
| **APS—Split sample** | | | | |
| Upgraded | -0.005 (0.731) | 0.036 (0.254) | 0.003 (0.891) | -0.032 (0.205) |
| Median speed | -0.0013* (0.028) | -0.0053* (0.000) | -0.0016* (0.041) | -0.0001 (0.927) |
| NGA | -0.024* (0.065) | -0.010 (0.728) | -0.018 (0.305) | -0.030 (0.210) |

Table note. Beta coefficients presented with p values in parenthesis; excluding Northern Ireland as this does not have postcode available within the APS; Standard Controls used; OLS regression conducted with heteroscedasticity-robust standard errors as is best practice in SWB analysis; a * indicates statistical significance at the 10% level; a threshold of 10% is used, as it is the typical threshold accepted for SWB analysis. Life satisfaction on a 0-10 scale. Data source: ONS.

# 9 Appendix 3. Fixed Effects estimation (USoc)

The USoc dataset has the added benefit of tracking individuals over time, which allows to further control for unobserved time-invariant individual fixed effects. Such effects may include personality or motivation, which are undoubtedly correlated with wellbeing and will bias the estimates if they are also correlated with broadband. In fixed effects estimation, one is only comparing the changes over time for the same individual that occur for wellbeing, broadband and the control variables with the aim of modelling a linear relationship among these. The comparison of pooled OLS and fixed effects estimates is presented in the table below. The main model with the upgraded treatment as the key independent variable seems to be robust to a fixed effects specification. This holds to a lesser extent for NGA and not at all for median speed.

Table 15: Comparison of pooled OLS and fixed effects results in USoc

| Treatment variable | pooled OLS | fixed effects |
|---|---|---|
| **All ages** | | |
| Upgraded | 0.071* (0.001) | 0.061* (0.037) |
| Median speed | 0.002* (0.058) | 0.001 (0.587) |
| NGA | 0.020 (0.295) | 0.035 (0.239) |
| **Age 16-35** | | |
| Upgraded | 0.061* (0.097) | 0.017 (0.683) |
| Median speed | 0.005* (0.003) | 0.001 (0.851) |
| NGA | 0.048* (0.091) | 0.030 (0.555) |
| **Age 36-64** | | |
| Upgraded | 0.069* (0.011) | 0.083* (0.003) |
| Median speed | 0.001 (0.313) | 0.003 (0.112) |
| NGA | 0.002 (0.921) | 0.064* (0.071) |
| **Age 65+** | | |
| Upgraded | 0.085* (0.025) | 0.053 (0.170) |
| Median speed | 0.001 (0.527) | -0.004 (0.209) |
| NGA | 0.028 (0.328) | -0.018 (0.716) |

Table note. Beta coefficients presented on a 1-7 scale, with p values in parenthesis; Standard Controls used; both regressions conducted with heteroscedasticity-robust standard errors as is best practice in SWB analysis; a * indicates statistical significance at the 10% level.

# 10 Appendix 4. Duration effects

There is a possibility that the impact of superfast broadband might change over time. This is either because the technology is not taken up by the resident households immediately, or because people adapt to the initial (positive or negative) shocks associated with the superfast upgrade. This hypothesis is investigated empirically by running regressions for each of our three treatment variables, where the variable is taken to reflect the state (median speed, upgraded status, NGA) one year before the interview. The state of the treatment variables less than a year before the interview, are also included as controls. The results are presented in the table below. If this is compared to the main results, one can see that the effect of the 'upgraded' variable, but not the other two, is persistent over time. On this basis, it is appropriate for BDUK to assume more than one year's worth of impact as an input to the benefits model.

Table 16: Duration effects—total and by age

| Treatment variable | Full model | Ages 35 and below | Ages 36-64 | Ages 65+ |
|---|---|---|---|---|
| **APS—Great Britain** | | | | |
| Upgraded | -0.006 (0.754) | 0.072* (0.064) | -0.025 (0331) | -0.045 (0.171) |
| Median speed | -0.0027* (0.014) | 0.0059* (0.051) | -0.0085* (0.000) | 0.0033* (0.050) |
| NGA | -0.032* (0.042) | -0.019 (0.569) | -0.029 (0.184) | -0.047* (0.099) |
| **USoc—all UK** | | | | |
| Upgraded | 0.086* (0.046) | 0.038 (0.643) | 0.084 (0.160) | 0.118 (0.153) |
| Median speed | -0.0031 (0.266) | -0.0017 (0.752) | -0.0030 (0.443) | -0.0051 (0.367) |
| NGA | -0.023 (0.751) | 0.061 (0.288) | -0.026 (0.554) | -0.103* (0.081) |

Table note. Beta coefficients presented with p values in parenthesis for variables lagged one year; Standard Controls plus contemporaneous values included in regression; OLS regression conducted with heteroscedasticity-robust standard errors as is best practice in SWB analysis; a * indicates statistical significance at the 10% level; Life satisfaction on a 0-10 scale (APS) and a 1-7 scale (USoc). Data source: ONS.

# 11 Appendix 5. Further sensitivity checks

To test the sensitivity of the results to measurement error, a few changes were introduced to our main model (analysing the wellbeing relationship with *upgraded*). The definition of the upgraded variable was changed by replacing the mean upgrade date in the LSOA as a comparison factor with the first and then the last upgrade date. The wellbeing coefficient of the upgrade goes down from 0.071 in the main model with the mean date of upgrade to 0.044 for the first date of upgrade and 0.045 to the last date of upgrade. All remain significant at the 10 per cent level. While these alternative specifications do not get rid of the measurement error, they can swing it in one direction or the other (understating or overstating the number of upgraded households respectively), and there is a positive and significant result at both ends of the spectrum.

To also specifically address the fact that a respondent whose postcode was never targeted by BDUK at all might be recorded as upgraded as a result of data from other postcodes in the LSOA (as missing values are ignored in the mean date of upgrade calculation), one alternative model restricts our analysis only to those LSOAs where **all** postcodes eventually got upgraded with BDUK funding. This results in a small change of the wellbeing correlation from 0.071 to 0.073, although it loses significance as the sample is reduced eight times from 107,591 to 13,119.

Finally, in an attempt to reduce measurement error, the sample is restricted to those LSOA that are more homogeneous in terms of internet speed (standard deviation < threshold). A threshold of 10 Mbps reduces the coefficient from 0.071 to 0.066, still significant at the 10% level. A narrower threshold of 5 Mbps further reduces the coefficient to 0.045, where it is no longer statistically significant.

# 12 Appendix 6. Instrumental variable analysis—example estimates

Instrumental variable analysis in the APS gave rise to inconsistent results with a very high degree of volatility. The magnitude of the coefficients was often high beyond reason; the standard errors were also very high and the estimated impact of the treatment variables was inconsistent (as it varies from positive to negative across different model specifications). Most of the results were also statistically insignificant. An example of IV-estimated coefficients can be found in Table 17; the remaining IV model outputs can be provided upon request.

The inconsistent estimation outputs are underpinned by theoretical considerations. We have good reasons to believe that the main assumptions required for instrumental variable validity are not fulfilled for our chosen instruments—cabinet size, share of exchange-only lines and cabinet-postcode distance. The exclusion restriction may not hold because the instruments are correlated with omitted factors such as 'remoteness' or 'concentration of economic activity,' which may also influence wellbeing. Some of the instruments are also weak—the share of exchange-only lines is barely significant as a determinant of upgrade status or speed in the first-stage regression, and it is also a remarkably skewed variable with low variation: over 90% of the sample has a value of 0 for this variable.

The inconsistent estimation outputs and the violation of IV assumptions lead to the recommendation that the IV analysis should be discarded as unsuitable for the subject matter of this study, given the data available.

Table 17: Example IV estimations

| Model type | Full model | Aged 35 and below | Aged 36-64 | Aged 65+ |
|---|---|---|---|---|
| Split sample, 2 instruments | -0.122 (0.575) | -1.021* (0.044) | -0.098 (0.738) | 0.168 (0.697) |
| Split sample, 3 instruments | -0.180 (0.323) | -1.022* (0.018) | -0.276 (0.282) | 0.267 (0.419) |
| Interactions, 4 instruments | N/A | 3.108 (0.847) | -1.198 (0.873) | 0.245 (0.969) |

Table note. The treatment variable is always the BDUK upgrade before interview ('upgraded'. Beta coefficients presented with p values in parenthesis; excluding Northern Ireland as this does not have postcode available within the APS; Standard Controls used; The instruments are: cabinet number of premises served and share of exchange-only lines (first line); distance from postcode to cabinet (second line); distance from postcode to exchange (third line). 2SLS regression conducted with heteroscedasticity-robust standard errors; a * indicates statistical significance at the 10% level; Dependent variable is life satisfaction on a 0-10 scale. Data source: ONS.

# 13 Appendix 7. Example of full regression output.

Below are the full outputs for the main regression model used in the APS dataset, with the upgraded variable at postcode level as the main explanatory variable, disaggregated by the three age categories using interaction terms. Full outputs of other models are available upon request.

| | beta coeff. | std. err. | t-stat | p-value | 95% CI low | 95% CI high | sample size |
|---|---|---|---|---|---|---|---|
| 1.upgraded#1b.age_cat | 0.078019 | 0.024568 | 3.175572 | 0.001496 | 0.029865 | 0.126172 | 169188 |
| 1.upgraded#2.age_cat | -0.03287 | 0.016636 | -1.97589 | 0.048169 | -0.06548 | -0.00026 | 169188 |
| 1.upgraded#3.age_cat | 0.000725 | 0.020548 | 0.035305 | 0.971837 | -0.03955 | 0.041 | 169188 |
| female | 0.079541 | 0.009461 | 8.407016 | 4.24E-17 | 0.060997 | 0.098084 | 169188 |
| age | -0.05794 | 0.002122 | -27.3104 | 7.3E-164 | -0.0621 | -0.05378 | 169188 |
| agesq | 0.000521 | 2.15E-05 | 24.18934 | 4.8E-129 | 0.000479 | 0.000563 | 169188 |
| 1b.ethnic | 0 | | | | | | 169188 |
| 2.ethnic | -0.05463 | 0.077307 | -0.70662 | 0.479806 | -0.20615 | 0.096893 | 169188 |
| 3.ethnic | -0.03371 | 0.039982 | -0.84319 | 0.399126 | -0.11207 | 0.044651 | 169188 |
| 5.ethnic | -0.17286 | 0.077859 | -2.22013 | 0.026411 | -0.32546 | -0.02026 | 169188 |
| 6.ethnic | -0.22908 | 0.081516 | -2.81028 | 0.00495 | -0.38885 | -0.06931 | 169188 |
| 11.ethnic | -0.68169 | 0.281733 | -2.41965 | 0.015537 | -1.23388 | -0.1295 | 169188 |
| 0b.religious | 0 | | | | | | 169188 |
| 1.religious | 0.126731 | 0.00976 | 12.98468 | 1.56E-38 | 0.107602 | 0.145861 | 169188 |
| 11.religious | -0.27354 | 0.148178 | -1.84602 | 0.064891 | -0.56397 | 0.016886 | 169188 |
| 1.cigsmk1 | -0.33397 | 0.014075 | -23.7282 | 3E-124 | -0.36156 | -0.30639 | 169188 |
| 2.cigsmk1 | -0.0748 | 0.008964 | -8.34434 | 7.21E-17 | -0.09236 | -0.05723 | 169188 |
| 3b.cigsmk1 | 0 | | | | | | 169188 |
| 6.cigsmk1 | -0.02625 | 0.058947 | -0.44524 | 0.656146 | -0.14178 | 0.08929 | 169188 |
| 9.cigsmk1 | -0.41078 | 0.181233 | -2.26658 | 0.023417 | -0.76599 | -0.05557 | 169188 |
| 1b.maritals | 0 | | | | | | 169188 |
| 2.maritals | 0.408798 | 0.01366 | 29.92577 | 3E-196 | 0.382024 | 0.435572 | 169188 |
| 3.maritals | -0.34406 | 0.030192 | -11.3958 | 4.5E-30 | -0.40324 | -0.28489 | 169188 |
| 4.maritals | -0.06307 | 0.018737 | -3.36599 | 0.000763 | -0.09979 | -0.02634 | 169188 |
| 5.maritals | -0.26529 | 0.022174 | -11.9638 | 5.67E-33 | -0.30875 | -0.22183 | 169188 |
| 6.maritals | 0.152625 | 0.097433 | 1.566464 | 0.117242 | -0.03834 | 0.343591 | 169188 |
| 1.education | -0.14061 | 0.020786 | -6.76477 | 1.34E-11 | -0.18135 | -0.09987 | 169188 |
| 2.education | -0.10594 | 0.022162 | -4.78056 | 1.75E-06 | -0.14938 | -0.06251 | 169188 |
| 3.education | -0.10599 | 0.021035 | -5.03878 | 4.69E-07 | -0.14722 | -0.06476 | 169188 |
| 4.education | -0.10864 | 0.021208 | -5.12251 | 3.02E-07 | -0.15021 | -0.06707 | 169188 |
| 5.education | -0.01731 | 0.025584 | -0.67642 | 0.498773 | -0.06745 | 0.032838 | 169188 |
| 6b.education | 0 | | | | | | 169188 |
| 7.education | -0.06591 | 0.028975 | -2.27492 | 0.022912 | -0.1227 | -0.00913 | 169188 |
| 1b.ten1 | 0 | | | | | | 169188 |
| 2.ten1 | -0.19664 | 0.011676 | -16.8405 | 1.39E-63 | -0.21952 | -0.17375 | 169188 |
| 3.ten1 | -0.29602 | 0.06417 | -4.6131 | 3.97E-06 | -0.42179 | -0.17025 | 169188 |
| 4.ten1 | -0.24586 | 0.016799 | -14.6355 | 1.79E-48 | -0.27878 | -0.21293 | 169188 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5.ten1 | 0.058341 | 0.038406 | 1.519058 | 0.12875 | -0.01693 | 0.133616 | 169188 |
| 6.ten1 | 0.042444 | 0.035726 | 1.188031 | 0.234823 | -0.02758 | 0.112466 | 169188 |
| 7.ten1 | -0.28594 | 0.017306 | -16.5225 | 2.82E-61 | -0.31986 | -0.25202 | 169188 |
| 11.ten1 | 0.083315 | 0.184614 | 0.451295 | 0.651777 | -0.27852 | 0.445155 | 169188 |
| 0.benefits | -0.43309 | 0.031276 | -13.8474 | 1.39E-43 | -0.49439 | -0.37179 | 169188 |
| 1b.benefits | 0 | | | | | | 169188 |
| 2.benefits | -0.14858 | 0.011948 | -12.4359 | 1.73E-35 | -0.172 | -0.12517 | 169188 |
| 0b.dchildren | 0 | | | | | | 169188 |
| 1.dchildren | 0.091884 | 0.015331 | 5.993437 | 2.06E-09 | 0.061836 | 0.121932 | 169188 |
| 2.dchildren | 0.093154 | 0.015977 | 5.830593 | 5.53E-09 | 0.06184 | 0.124467 | 169188 |
| 3.dchildren | 0.141928 | 0.025373 | 5.593694 | 2.23E-08 | 0.092198 | 0.191659 | 169188 |
| 4.dchildren | 0.116763 | 0.047494 | 2.458484 | 0.013954 | 0.023676 | 0.20985 | 169188 |
| 1b.employment3 | 0 | | | | | | 169188 |
| 2.employment3 | 0.059 | 0.02744 | 2.150133 | 0.031546 | 0.005218 | 0.112782 | 169188 |
| 3.employment3 | -0.99011 | 0.140024 | -7.07098 | 1.54E-12 | -1.26455 | -0.71566 | 169188 |
| 4.employment3 | 0.098467 | 0.065545 | 1.502286 | 0.133025 | -0.03 | 0.226934 | 169188 |
| 5.employment3 | -0.86753 | 0.03807 | -22.7881 | 9E-115 | -0.94215 | -0.79292 | 169188 |
| 6.employment3 | -0.06719 | 0.043996 | -1.52723 | 0.126706 | -0.15342 | 0.019039 | 169188 |
| 7.employment3 | -0.04862 | 0.0318 | -1.52887 | 0.126298 | -0.11095 | 0.013709 | 169188 |
| 8.employment3 | -1.37295 | 0.091935 | -14.9339 | 2.14E-50 | -1.55314 | -1.19276 | 169188 |
| 9.employment3 | -1.4339 | 0.03645 | -39.339 | 0 | -1.50534 | -1.36245 | 169188 |
| 10.employment3 | -0.67121 | 0.141336 | -4.74908 | 2.05E-06 | -0.94823 | -0.3942 | 169188 |
| 11.employment3 | 0.354023 | 0.027097 | 13.06499 | 5.45E-39 | 0.300913 | 0.407132 | 169188 |
| 12.employment3 | 0.536455 | 0.040697 | 13.18176 | 1.17E-39 | 0.45669 | 0.61622 | 169188 |
| 13.employment3 | -0.67564 | 0.121764 | -5.54878 | 2.88E-08 | -0.9143 | -0.43699 | 169188 |
| 14.employment3 | -0.29911 | 0.055729 | -5.36729 | 8E-08 | -0.40834 | -0.18989 | 169188 |
| 15.employment3 | 0.1177 | 0.025117 | 4.686152 | 2.79E-06 | 0.068472 | 0.166928 | 169188 |
| 16.employment3 | 0.229501 | 0.03086 | 7.436929 | 1.04E-13 | 0.169017 | 0.289985 | 169188 |
| 17.employment3 | -0.33607 | 0.038118 | -8.81646 | 1.19E-18 | -0.41078 | -0.26136 | 169188 |
| 18.employment3 | -0.05279 | 0.028874 | -1.82829 | 0.067508 | -0.10938 | 0.003802 | 169188 |
| 19.employment3 | 0.030497 | 0.027617 | 1.104256 | 0.269484 | -0.02363 | 0.084626 | 169188 |
| 20.employment3 | 0.069276 | 0.027308 | 2.53688 | 0.011185 | 0.015754 | 0.122798 | 169188 |
| 21.employment3 | 0.11369 | 0.026146 | 4.34831 | 1.37E-05 | 0.062445 | 0.164934 | 169188 |
| 22.employment3 | 0.177252 | 0.026373 | 6.720987 | 1.81E-11 | 0.125562 | 0.228942 | 169188 |
| 1b.rurality2 | 0 | | | | | | 169188 |
| 2.rurality2 | 0.044418 | 0.010348 | 4.292627 | 1.77E-05 | 0.024137 | 0.064699 | 169188 |
| 1b.gora | 0 | | | | | | 169188 |
| 2.gora | 0.045407 | 0.02939 | 1.544973 | 0.122355 | -0.0122 | 0.10301 | 169188 |
| 3.gora | 0.071714 | 0.029421 | 2.43753 | 0.014789 | 0.01405 | 0.129378 | 169188 |
| 4.gora | 0.043322 | 0.030333 | 1.428221 | 0.15323 | -0.01613 | 0.102774 | 169188 |
| 5.gora | -0.01688 | 0.029436 | -0.5733 | 0.566445 | -0.07457 | 0.040819 | 169188 |
| 6.gora | 0.025525 | 0.029357 | 0.869461 | 0.384596 | -0.03201 | 0.083063 | 169188 |
| 8.gora | 0.036068 | 0.02811 | 1.283066 | 0.199471 | -0.01903 | 0.091163 | 169188 |
| 9.gora | 0.042751 | 0.028243 | 1.513651 | 0.130116 | -0.01261 | 0.098107 | 169188 |
| 10.gora | -0.0012 | 0.025411 | -0.04721 | 0.962345 | -0.05101 | 0.048606 | 169188 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 11.gora | 0.167206 | 0.025847 | 6.469176 | 9.88E-11 | 0.116547 | 0.217865 | 169188 |
| facetoface | -0.05738 | 0.008656 | -6.62885 | 3.39E-11 | -0.07435 | -0.04041 | 169188 |
| 1b.refwkm | 0 | | | | | | 169188 |
| 2.refwkm | 0.004634 | 0.02044 | 0.226716 | 0.820645 | -0.03543 | 0.044697 | 169188 |
| 3.refwkm | -0.00626 | 0.019644 | -0.31853 | 0.75008 | -0.04476 | 0.032244 | 169188 |
| 4.refwkm | 0.003255 | 0.020716 | 0.157137 | 0.875137 | -0.03735 | 0.043859 | 169188 |
| 5.refwkm | -0.00227 | 0.020693 | -0.10964 | 0.912697 | -0.04283 | 0.03829 | 169188 |
| 6.refwkm | 0.018662 | 0.02018 | 0.924816 | 0.355063 | -0.02089 | 0.058214 | 169188 |
| 7.refwkm | 0.004941 | 0.020482 | 0.241231 | 0.809376 | -0.0352 | 0.045085 | 169188 |
| 8.refwkm | 0.051283 | 0.020111 | 2.549956 | 0.010775 | 0.011865 | 0.090701 | 169188 |
| 9.refwkm | -0.00205 | 0.020299 | -0.1012 | 0.919395 | -0.04184 | 0.037731 | 169188 |
| 10.refwkm | -0.00771 | 0.020657 | -0.37333 | 0.708905 | -0.0482 | 0.032776 | 169188 |
| 11.refwkm | -0.00555 | 0.020314 | -0.27342 | 0.784531 | -0.04537 | 0.03426 | 169188 |
| 12.refwkm | 0.050909 | 0.019979 | 2.548159 | 0.01083 | 0.011751 | 0.090066 | 169188 |
| 1b.wave | 0 | | | | | | 169188 |
| 2.wave | 0.027084 | 0.013408 | 2.01998 | 0.043387 | 0.000805 | 0.053364 | 169188 |
| 3.wave | 0.066642 | 0.013358 | 4.988956 | 6.08E-07 | 0.040461 | 0.092824 | 169188 |
| 4.wave | 0.140765 | 0.014448 | 9.742829 | 2.01E-22 | 0.112447 | 0.169083 | 169188 |
| 5.wave | 0.176862 | 0.016576 | 10.67002 | 1.43E-26 | 0.144374 | 0.20935 | 169188 |
| lsoa_popden | -0.00123 | 0.000261 | -4.73318 | 2.21E-06 | -0.00175 | -0.00072 | 169188 |
| _cons | 9.063285 | 0.066889 | 135.4969 | 0 | 8.932183 | 9.194386 | 169188 |

Data source: ONS.

# 14 Appendix 8. Control variables

Table 18. Control variables used in the analysis

| Control variable | Reason for inclusion in the model[40] |
|---|---|
| **Earnings (APS for employed only)[41] / Household income (USoc)** | Income has been widely studied as a determinant of life satisfaction as it can be exchanged for goods and services from which individuals derive utility. Diminishing marginal utility of income is accounted for by taking the natural logarithm of equivalised household income. The APS only provides wage income for the employed, not household income. |
| **Age, age squared** | The wellbeing literature has established a U-shaped relationship between age and wellbeing, which reached its minimum levels for the middle-aged. Alternative model specifications replace these with 5-year and 10-year age bands. |

[40] References can be found in Dolan and Metcalfe (2008)

[41] The APS does not have a household income variable, but only "earnings in main job."

| | |
|---|---|
| **Gender** | The literature indicates that females are happier than males, all other things equal.[42] |
| **Marital status** | Getting married has a considerable impact on a person's wellbeing. |
| **Number of children** | Having children positively affects wellbeing, with diminishing returns for each successive child. |
| **Ethnicity** | This adjusts for average differences in experience and responses to the life satisfaction scales amongst ethnic groups. |
| **Educational status** | A person's level of education significantly affects the life opportunities available to them (positive wellbeing correlation). |
| **Employment status** | This can have a strong impact on wellbeing, particularly for states such as unemployment, retirement, or being unable to work due to disability. |
| **Religiousness** | Faith and belief are associated with increased life satisfaction. |
| **House ownership** | Owning a house (as opposed to renting it or paying a mortgage) is associated with increased wellbeing and is also partially a proxy for wealth. |
| **Urbanisation** | Living in an urban area is associated with lower wellbeing, probably due to the increased levels of stress in urban life. |
| **Population density** | As an extension of the above, we control for population density as it also a key factor which defined eligibility for BDUK upgrades. |
| **Region** | This is captures regional variations in economic development and lifestyles. |
| **Wave of survey** | This is to control for the overall upward trend in wellbeing in the APS / USoc. |
| **Month of interview** | Momentary experiences such as weather or holidays tend to affect responses to evaluative wellbeing questions (life satisfaction) as well. The month of interview controls for this to some extent. |
| **Claiming benefits** | This is used as a proxy for lower socio-economic status. |
| **Smoking** | Smoking is associated with lower wellbeing. |
| **Survey mode (face-to-face vs. telephone)** | Face-to-face interviews result in systematically lower wellbeing due to interviewer effects. |

[42] For instance, see: https://www.ons.gov.uk/peoplepopulationandcommunity/wellbeing/bulletins/measuringnationalwellbeing/october2016toseptember2017