
An econometric analysis of pricing trends in the UK

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About this document

In monitoring whether the mobile sector continues to deliver favourable outcomes for consumers choosing to move or adopt new tariff plans, there are contrasting views on recent UK mobile pricing trends. Assessing trends in mobile prices is a complex task because of the degree of differentiation in tariffs offered by mobile operators. Price differences between mobile operators or between different tariffs of the same operator may simply reflect differences in the tariff characteristics or handset.

This document sets out our analysis of mobile pricing trends in the UK for tariffs that were available between 2013 and 2017. Given the difficulties with directly comparing mobile contracts, we have undertaken an econometric approach which controls for the different elements of available tariffs, and their associated handsets. This allows us to identify underlying pricing trends for consumers choosing to move or adopt new tariff plans. It does not include tariffs which were removed from the market before this period (which consumers may have remained on).

Contents

Section

1. Overview	3
2. Mobile pricing in the UK	7
3. Hedonic pricing approach	12
4. Features of mobile plans and data sources	17
5. Results	24
6. Potential limitations	30

Annexes

A1. Specifying variables in our analysis	37
A2. Estimation Results	41
A3. Robustness Testing	53

1. Overview

The UK mobile sector has a few large competing firms

- 1.1 In markets with relatively few large competing firms, there is a risk of consumer harm. Consumer harm in concentrated markets can arise even without a single dominant company or companies engaging in overt collusion. It may take the form of prices being substantially above costs or product quality being low.
- 1.2 The UK mobile communications sector has relatively few large competing firms. However, the nature of mobile investment and competition has meant that, generally, we have been able to rely on end-to-end competition to deliver good outcomes for mobile users in terms of both variety of offerings and competitive prices.

There are contrasting views on recent UK mobile pricing trends

- 1.3 In monitoring whether the mobile sector continues to work for consumers choosing to move or adopt new tariff plans, there has been some conflicting evidence on recent UK mobile pricing trends. Assessing trends in mobile prices is a complex task because of the degree of differentiation in tariffs offered by mobile operators.
- 1.4 Recently, both Frontier Economics¹ and Enders Analysis² have argued that UK mobile prices available to consumers choosing to move or adopt new tariff plans have increased in recent times, whereas our analysis has tended to find that these prices have been falling or have remained flat³.
- 1.5 In our 2017 Statement on the Award of the 2.3GHz and 3.4GHz spectrum⁴ bands, we discussed our concerns with the analysis undertaken by Frontier Economics, and our consideration that we could not rely on it⁵. We also noted that there are limitations with the approach that we have taken in the past based on assessing the prices of representative baskets. We discuss this approach and its limitations in Section 3.

¹ [Annex 21 to H3G's response to the PSSR Consultation](#). Using the basket approach (discussed in paragraphs 2.11-2.12) and econometric analysis (discussed in Section 3), Frontier estimated that prices of tariffs with handsets increased by 13% and 15% respectively between 2014 and 2016. Using the basket approach, Frontier also estimated that prices of SIM-only tariffs fell by 16% over the same period.

² [Covert Growth in UK mobile](#), 2018. This analysis tracks advertised prices and finds that the price of a (loosely defined) tariff with the latest available iPhone handset increased in 2018.

³ See, for example Ofcom [ICMR 2016](#): This analysis found that the weighted average price of eight standalone mobile connections fell by 38% between 2015 and 2016. [Award of the 2.3 and 3.4 GHz spectrum bands Consultation](#): This basket analysis found that the weighted average prices of plans with handsets were generally flat between 2014 and 2016. [2018 Pricing Report](#): This analysis suggests that the weighted average cost of the average mobile basket (excluding handsets) fell by 12% between 2013 and 2017.

⁴ [Award of the 2.3 and 3.4 GHz spectrum bands: Annexes to the statement](#)

⁵ We have a number of concerns with Frontier Economics' analysis. For example, neither their basket or econometric approach distinguishes between plans that offer 3G versus 4G technology. The pricing analysis by Enders Analysis is also very high-level as it appears to follow the price of just one (loosely-defined) tariff over time. This is not representative of all available tariffs and so does not shed much light on the trends in prices actually faced by consumers.

We have undertaken analysis to contribute to the discussion on UK mobile pricing

- 1.6 Given the limitations we have identified with previous approaches to estimating mobile prices in the UK, we have looked to undertake an econometric analysis of the UK mobile market to shed more light on recent pricing trends of tariffs available in the market. This analysis corrects some of the limitations of our basket approach and attempts to address the concerns we had with the analysis by Frontier Economics. However, as we discuss in Section 6, we recognise that our analysis also has a number of limitations, meaning that it should be used to complement our existing approach rather than to replace it.
- 1.7 Our analysis of UK pricing trends spans five years from 2013 to 2017. This is broadly consistent with the analysis by Frontier Economics which considered tariffs between 2013 and 2016. We consider this to be an appropriate time period since it broadly captures the years after 4G tariffs became widely available to UK consumers.
- 1.8 Our analysis focuses on the available tariffs in the market and is therefore an indicator of competitiveness for consumers choosing to move or adopt new tariff plans. It does not include tariffs which were discontinued before this period (which consumers may have remained on). As such, it does not deal with broader consumer welfare questions (for example, consumers continuing to pay handset repayments although they are out-of-contract).

Our econometric analysis suggests that UK mobile prices available between 2013 to 2017 have been falling over time

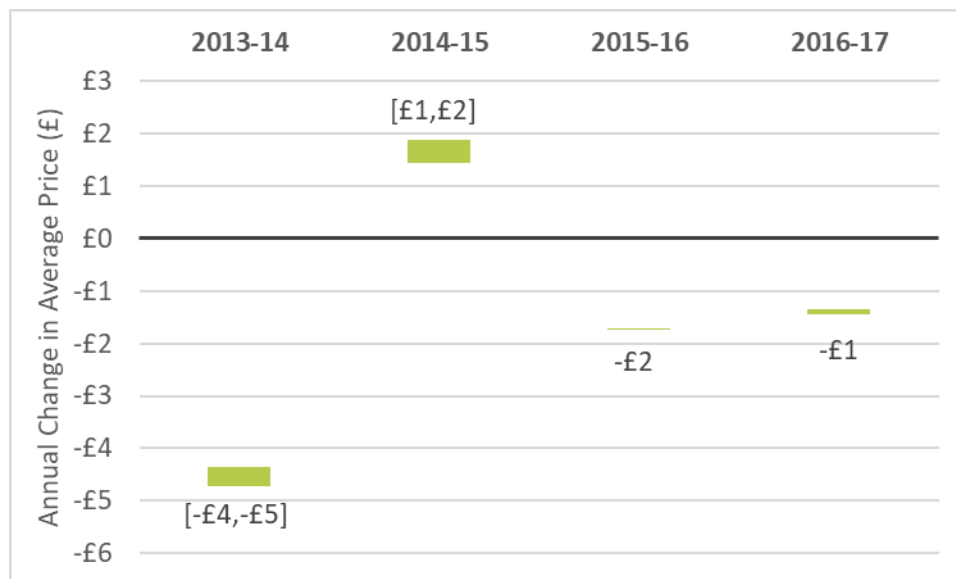
- 1.9 In analysing pricing trends in the UK mobile market, we have undertaken an econometric regression analysis which allows us to compare mobile prices, controlling for relevant product features, handset quality, firm-specific characteristics and time critical factors.
- 1.10 Figure 1.1 below reports the estimated yearly change in the prices of post-pay (i.e. pay monthly) mobile tariffs including handsets between 2013 and 2017.⁶ Our analysis is based on tariffs with inclusive data allowances less than or equal to 20GB.⁷ We have estimated a range for the change in prices, represented in the graph below by the upper and lower bounds of the green shaded area.⁸

⁶ We have also estimated the yearly changes in the prices of mobile tariffs based on SIM-only tariffs which are broadly similar to those for tariffs with handsets – see Annex 2. However, this analysis is based on a more limited dataset.

⁷ Our Connected Nations report shows that average monthly data usage per person in 2017 was 1.9GB, indicating that many consumers do not require data allowances in excess of 20GB per month. This suggests that our decision to exclude tariffs with higher data allowances does not lead to a dataset which is unrepresentative of the prices paid by the wider population. However, as a sensitivity test, we also ran the analysis for the full set of observations, including all tariffs with high data allowances – see Annex 2. The overall downward price trend remained the same.

⁸ The relationship between price and quality is not linear so we estimate our results using two functional forms. We note that using these two different functional forms does not significantly change our results. However, we have chosen to estimate our results based on these two functional forms, because they allow us to obtain lower and upper bounds for our price trends – see Annex 3.

Figure 1.1: UK mobile price trends for available post-pay plans including handsets for each year

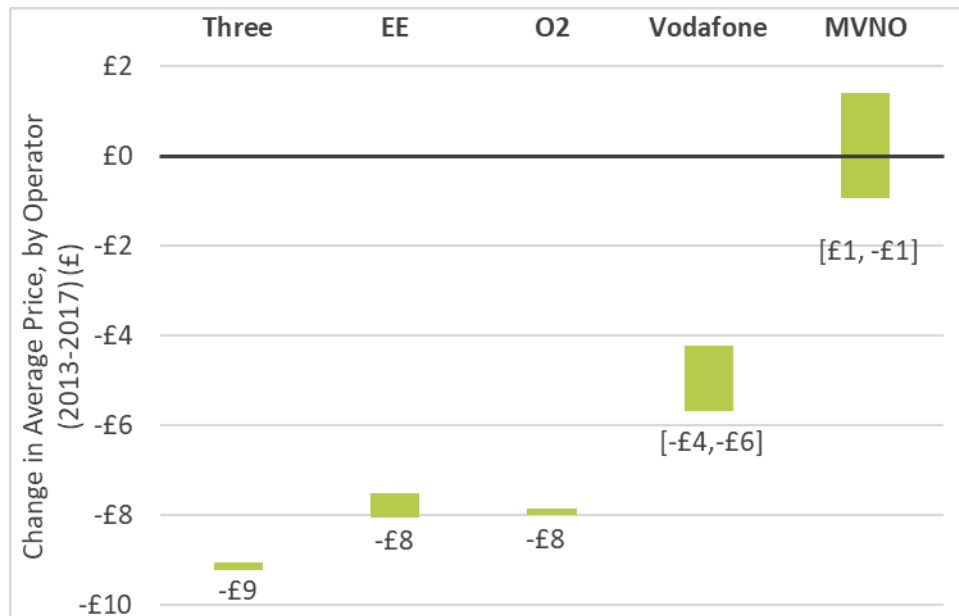


1.11 While we appreciate that there may be a number of potential limitations with the analysis, our findings support the proposition that the general trend of available prices available in the market over the period in question is falling over time (with the exception of between 2014 and 2015⁹). This suggests that consumers are either able to receive improved services without having to pay proportionally more or can consume the same services for less money over time. We therefore consider that given prices are continuing to fall overall over the period, and consumers are not forcibly being migrated, the mobile sector is continuing to work in favour of consumers. We recognise, however, that there are multiple indicators of competitiveness, and so this analysis should not be viewed in isolation. In particular, our analysis does not speak to broader consumer welfare questions (for example, consumers continuing to pay handset repayments although they are out-of-contract).

1.12 Figure 1.2 below reports the estimated pricing trend separately for each operator. Our findings suggest that the average change in prices for tariffs that were available in the market over the period in question varied across the operators. Three’s available tariffs have become significantly more competitive over the period, whereas prices for tariffs available in the market during 2013 and 2017 for O2, EE and Vodafone have declined more slowly, all else equal. The results are mixed for mobile virtual network operators (MVNOs). Based on our main specification, presented as the lower bound of the range below, we estimate that MVNOs’ prices for tariffs plans available between 2013 and 2017 have on average reduced.

⁹ As we discuss in Section 5, this effect was also observed in the PSSR spectrum release consultation where we considered that the price increase was possibly explained by an increase in price of premium handsets and the additional costs of 4G packages.

Figure 1.2: UK mobile price trends for available post-pay plans including handsets for 2013-2017, by operator



We discuss our approach and results in more detail in the rest of this document

1.13 The outline of this paper is as follows:

- a) Section 2 provides a brief discussion of mobile pricing in the UK, the difficulty of directly comparing prices and approaches to carry out like-for-like comparisons of tariffs for the purpose of assessing pricing trends;
- b) Section 3 sets out the hedonic pricing approach that we use in this paper;
- c) Section 4 describes some of the pertinent characteristics of mobile offerings that we consider affect mobile tariff prices and sets out the data sources we have used for the analysis;
- d) we present our results in Section 5; and
- e) Section 6 discusses the possible limitations of our analysis.

2. Mobile pricing in the UK

Mobile operators tailor tariffs to meet the diverse tastes of consumers

- 2.1 The UK mobile market is characterised by four mobile network operators (MNOs) as well as a number of MVNOs, each offering a range of tariff plans. These plans can be broadly divided into three categories:
- a) Pre-pay plans where consumers pre-pay for credit to make calls, send texts or use data on their pre-bought mobile phones. These tariffs have become less popular over time with 24% of consumers taking pre-paid plans in 2018¹⁰, down from 53% in 2010.¹¹
 - b) Post-pay SIM-only plans where consumers pay a pre-determined amount each month to receive a certain number of inclusive minutes, texts and data at no extra cost on their pre-bought phones. These tariffs have become increasingly popular over time, representing approximately 19% of connections in 2018, up from 6% in 2012.¹²
 - c) Post-pay plans including handsets where the mobile operator provides the consumer with the handset in addition to an allowance of inclusive minutes, texts and data. These plans may charge an upfront fee to cover some or all of the cost of the phone with any remaining cost being included in the monthly price.
- 2.2 Given the diverse tastes of mobile consumers, in competing for customers, operators vary their offerings along many dimensions. Prices of mobile tariffs therefore vary depending on the make-up of individual plans.

Differentiated mobile tariffs means that it is difficult to compare mobile prices available in the market

- 2.3 Table 2.1 below provides a snapshot (from 11 May 2017) of some of the key dimensions of current post-pay tariffs with a selection of handsets taken from the four MNO websites.
- 2.4 As can be observed from Table 2.1, given the degree of differentiation in tariffs offered by providers, it is difficult to directly compare prices since they vary depending on the make-up of individual plans. For example, a number of factors can affect the price of a particular mobile tariff including the contract length, volume of minutes, texts and data allowances.
- 2.5 Simple price differences between MNOs with differentiated offerings or between different tariff plans of the same MNO may merely reflect differences in the quantity or quality of services or handsets. Moreover, even for an equal bundle allowance, such as EE in the

¹⁰ [Pricing trends for communications services in the UK](#), 2018, Figure 10.

¹¹ [Award of the 2.3 and 3.4 GHz spectrum bands](#), 2017, paragraph A1.82.

¹² [Pricing trends for communications services in the UK](#), 2018, Figure 11.

table below, comparison may be complicated due to differing upfront costs paid towards the handset, which in turn affect the monthly cost.

Table 2.1: Examples of post-paid plans including handsets offered by MNOs

Handset	EE		O2		H3G		Vodafone	
	Apple iPhone X 64GB		Apple iPhone SE 32GB		Samsung Galaxy 9 64GB		Apple iPhone X 64GB	
	Plan 1	Plan 2	Plan 1	Plan 2	Plan 1	Plan 2	Plan 1	Plan 2
Contract length (mths)	24	24	24	24	24	24	24	24
Upfront cost	£150.00	£50.00	£89.99	£0.00	£79.00	£0.00	£199.00	£99.00
Monthly cost	£73.00	£78.00	£18.00	£33.00	£52.00	£84.00	£63.00	£69.00
Minutes	Unltd	Unltd	500	Unltd	Unltd	Unltd	Unltd	Unltd
Texts	Unltd	Unltd	Unltd	Unltd	Unltd	Unltd	Unltd	Unltd
Data	20GB	20GB	500MB	15GB	30GB	Unltd	1GB	4GB

Sources: *Three website*, accessed 11 May 2018. *EE website*, accessed 11 May 2018. *O2 website*, accessed 11 May 2018. *Vodafone website*, accessed 11 May 2018.

- 2.6 This demonstrates the difficulties involved with comparisons at a single point in time. This is compounded further when considering how prices behave over time, since we need to control for changing bundle allowances and handsets over time.
- 2.7 Table 2.2 illustrates this time dimension. Specifically, it sets out the trends in average prices for given data allowances for tariffs plans that were available in the market between 2013 and 2017. It is based on the detailed raw pricing data used in our econometric analysis.

Table 2.2: Average price trends over time for selected data allowances (2013-2017)

	2013-14	2014-15	2015-16	2016-17	2013-17
500MB	-10%	-6%	-5%	4%	-16%
1GB	-13%	-1%	-3%	-4%	-20%
2GB	-13%	-5%	-2%	-9%	-26%
3GB	-20%	10%	-8%	-3%	-21%
4GB	-12%	-2%	-6%	-11%	-28%
5GB	-15%	-2%	-3%	-7%	-25%
6GB	-11%	19%	0%	-3%	-3%
8GB	-14%	4%	-10%	-8%	-26%
10GB	4%	2%	1%	-11%	-4%
12GB	-3%	-3%	-1%	-6%	-13%
20GB	-15%	4%	-4%	-13%	-26%
50GB	1%	7%	-2%	-1%	4%
Unlimited	3%	22%	20%	1%	51%

Source: Ofcom estimates based on data provided by Strategy Analytics. These estimates are based on data for available post-pay tariffs with handsets only.

2.8 The values in black correspond to decreases in prices with respect to the previous year while those in red refer to average price increases. As can be observed, while most average prices by data allowance for tariffs plans that were available in the market between 2013 and 2017 have declined, this has not been universal. Some average prices by data allowance have risen.

2.9 It is worth noting though that while this shows the changes in the average prices of plans with the same data allowance, there are other characteristics that could be changing over time that are not observed here.¹³ For this reason, it is difficult to draw conclusions about broad price trends for consumers choosing to move or adopt new tariff plans when comparing tariffs in this way because this does not provide a like-for-like comparison.

Two approaches allow for like-for-like comparison of tariffs

2.10 Given the discussion above, to directly compare available tariffs with each other for the purposes of assessing price trends for consumers choosing to move or adopt new tariff plans, two approaches can be used:

¹³ Note that the average price trends do not take into account other dimensions such as contract length, device included, provider of the service and minutes and SMS allowances, among others. Furthermore, for each data allowance the number of observations between different years changes as some plans disappear while new ones are launched.

- a) The first is a basket analysis where tariff plans are categorised and assessed as a group.
- b) The second is econometric analysis where all tariff plans available in a period are taken into account in an attempt to isolate pure price changes from changes that relate to other differences.

The basket approach is useful but it suffers from some limitations

- 2.11 A methodology we have previously used to compare mobile prices in the UK for consumers choosing to move or adopt new tariff plans is based on representative baskets.¹⁴ Under this approach, we construct hypothetical usage baskets, consisting of a combination of voice calls, SMS text messages and data usage volumes, to broadly represent mobile service usage across different types of consumers.
- 2.12 We then determine the best prices available at a point in time to buy these baskets from the largest mobile providers in the market, and using retail market shares, obtain an estimated weighted average price for those usage baskets. This analysis has indicated that mobile tariff prices for consumers choosing to move or adopt new tariff plans have tended to fall over time.¹⁵
- 2.13 The basket approach is a useful way to compare pricing of communications services but it also has a number of limitations:
 - a) the focus of the basket approach is to select prices from the largest mobile providers but there is a much wider range of options available to consumers than those included in the baskets;
 - b) to ensure comparability across time, the same usage baskets are often used to analyse prices but this does not then take account of the evolving nature of how consumers use mobile services;
 - c) to calculate the 'weighted average' price, the model uses operators' overall retail customer market share and not the subscriber base for the particular tariff as those figures are not available. This essentially means that the same weight is applied to each usage basket. This is a reasonable assumption to make in the absence of better information but it means that it has limitations which are relevant when interpreting the overall price change. This is especially relevant if the prices of different baskets are changing at very different rates or are moving in different directions; and
 - d) the basket approach is based on the assumption of a rational consumer who shops around for the best value tariff. The analysis, therefore, considers only the lowest available price for each basket when, in reality, many consumers do not act in this way and so only a proportion will be on the cheapest tariff for their usage level.

¹⁴ See [Pricing Report 2018](#), Annex 1.

¹⁵ This analysis suggests that the weighted average cost of the average basket (excluding handsets) fell by 12% between 2013 and 2017. See [Pricing Report 2018](#), Figure 4.

The econometric approach corrects some of these limitations

- 2.14 An alternative approach to assessing changes in mobile prices for consumers choosing to move or adopt new tariff plans is an econometric approach, using an estimation method called hedonic pricing analysis.
- 2.15 This method allows one to compare prices across products and time by decomposing price differences into price differences that are accounted for by quality differences and those that are accounted for by changing market conditions.
- 2.16 There are a number of advantages to this approach:
- a) It allows us to carry out a like-for-like comparison across products and across time, and therefore take into account the evolving nature of how consumers use mobile services, unlike the basket approach – see discussion at 2.13 b).
 - b) It is relatively straightforward to apply, because it is based on actual (or published) prices and product characteristics that are generally readily available.
 - c) It resolves some of the limitations of the basket approach. For example, by taking into account all tariff plans (not just the plans from the largest mobile providers) it resolves the issue discussed at 2.13 a) above. It can also consider a wider range of prices, which can address d).
- 2.17 Given that the econometric approach corrects some of the limitations of the basket approach, the focus of this paper is to use the hedonic estimation method to estimate mobile pricing trends for tariffs that were available in the market between 2013 and 2017 and to use this as a complementary piece of analysis to our most recent pricing report based on the basket approach. In the next section, we describe this approach in more detail.

3. Hedonic pricing approach

Hedonic pricing analysis allows for a like-for-like comparison of tariffs across products and across time and is used extensively

- 3.1 As discussed in Section 2, comparing prices across mobile plans and time is a complex task as operators vary their offerings along many dimensions. Given the diverse tastes of consumers, prices vary depending on the make-up of individual plans. This makes it difficult to directly compare tariffs.
- 3.2 To separate price changes on a like-for-like basis from other quality or market differences, we can use an estimation method called hedonic pricing analysis. This technique has been used extensively to compare the price of products whose quality changes over time or product space. For example, it has been applied to products such as automobiles (Brenkers & Verboven, 2005¹⁶; Berry, Levinsohn & Pakes, 2004¹⁷), mobile communications (Dewenter, Haucap, Luther & Rötzel, 2007¹⁸; Forenbacher, Peraković, Husnjak, 2016¹⁹) and has been used by the ONS to calculate quality adjustments for the smartphone component of CPI figures²⁰ amongst many others.

Prices of differentiated products are decomposed to reflect quality and firm-specific factors and changing market conditions

- 3.3 The basic premise of hedonic pricing is that the value of a marketed good is related to its characteristics, or the services it provides. All else equal, higher quality products, with higher quality characteristics or services, will have higher prices.
- 3.4 The technique is grounded in Lancaster's (1971) theory of consumption,²¹ where a product consists of various characteristics that customers value. As a consequence, we can think of the product's total price as being the sum of the prices derived from the value of each characteristic. The price of a certain characteristic is, therefore, regarded as a hedonic price so that a product's total price may be decomposed into the product's single characteristics' prices, determining the consumer's willingness to pay for each characteristic (Rosen, 1974).²²

¹⁶ Brenkers, R. & Verboven, F. (2005). Market definition with Differentiated Products- Lessons from the Car Market. CEPR Discussion Papers 5249, C.E.P.R.

¹⁷ Berry, S., Levinsohn, J., & Pakes, A. (2004). Differentiated products demand systems from combination of micro and macro data: the new car market. *Journal of Political Economy*, 112, 68-105.

¹⁸ Dewenter, R., Haucap, J., Luther, R., & Rötzel, P. (2007). Hedonic prices in the German market for mobile phones. *Telecommunications Policy*, 31(1),4-13.

¹⁹ Forenbacher, I., Peraković, D. & Husnjak, S. (2016). Hedonic modelling to explore the relationship of cell phone plan price and quality in Croatia, *Telematics and Informatics*, 33(4), 1057-1070.

²⁰ Abdurahman, M., Coyle, D., Heys, R. & Stewart, W. (2017). A Comparison of Approaches to Deflating Telecoms Services Output. Office for National Statistics (UK), University of Manchester & The Institution of Engineering and Technology.

²¹ Lancaster, K. (1971). *Consumer demand*. New York: Columbia University Press.

²² Rosen, S. (1974), "Hedonic prices and implicit markets", *Journal of Political Economy*, 82, 34-55.

- 3.5 In other words, the price of a car reflects the characteristics of that car- speed, fuel economy etc. Therefore, the individual characteristics (or combination of characteristics) of a car or other good can be valued by looking at how the price people are willing to pay changes when the characteristics change.

The hedonic price approach is a particular kind of regression analysis

- 3.6 The hedonic pricing approach is a particular kind of regression analysis. This regression is basically a function that explains the price of a service or product by the quality features (or characteristics) of that service or product. In the present context, the different components of mobile tariffs can be considered the “quality features”.
- 3.7 To obtain estimates of the contributory value of each “quality feature” requires that the composite good being valued can be reduced to its constituent parts and that the market values those constituent parts. The identification of relevant product features is therefore important. In particular, when comparing the prices of two products, it may be differences in quality features that drive the price differences. However, it may also be that the firm’s identity is unique - the contributory value of this can be determined by a firm-specific variable (Dewenter, Haucap, Luther & Rötzel, 2007).²³ When comparing product prices over time, it may not only be quality differences and firm identity but also changing market conditions.
- 3.8 On the basis that relevant product, firm and market features can be identified, the typical hedonic relationship for a product offering is:

$$p_{it} = f(X_{it}, \beta) + u_{it} \quad (1)$$

- 3.9 In this function, p_{it} is the price observation of the product i at time t where $i = 1, \dots, n$ and $t = 1, \dots, T$. X_{it} is a vector of characteristics for product i at time t , β is a parameter vector that needs to be estimated and u_{it} is a vector of disturbance terms.

We estimate how much price changes over time controlling for product and firm-specific features

- 3.10 Using the data (discussed in the next section), we estimate several versions of equation (1). The most basic version is the model in which we measure the unique effect of the characteristics on price:
- 3.11
$$p_{iot} = \tau + \sum_{k=1}^K \alpha_k Q_{kiot} + \sum_{t=1}^T \beta_t Time_t + \sum_{o=1}^O \gamma_o Operator_o + \varepsilon_{iot} \quad (2)$$
- 3.12 In this model, each coefficient measures the portion of the firms’ products’ prices that is attributable to each characteristic.²⁴

²³ See footnote 18.

²⁴ This specific interpretation only holds if (1) is linear. Here we have assumed this notation and this functional form for the sake of simplicity. As noted in Annex 3, different functional forms should be tested when carrying out hedonic estimations.

- 3.13 In equation (2), p_{iot} is the monthly price related to each tariff plan observation i offered by operator o at time t .
- 3.14 τ is an intercept term in our regression analysis and is the expected mean value of p_{iot} when all characteristics for product i by operator o at time t are equal to zero. Given that a number of our characteristics are dummy variables – see paragraph 4.5 – τ has an important role as representing the reference group when dummy coded variables have values of 0 – see discussion in paragraph A2.5.
- 3.15 Q_{kiot} are quality variables related to each tariff observation i by operator o at time t . The specification includes a total of K quality variables with k representing each individual quality variable. In our analysis, Q_{kiot} relates to the relevant features which we consider could have an effect on mobile tariff prices. For example, the monthly allowances of texts, data and voice minutes associated with each monthly tariff, the contract length, handset etc. If we want an estimate of how much price p_{iot} changes if one of the quality variables changes, holding everything else constant, then this is equivalent to the hedonic price $(\partial p_{iot})/(\partial Q_{kiot}) = \alpha_k$.
- 3.16 *Time* is a year fixed effect. The specification includes a total of T time periods with t representing each individual time period. Since the aim of our analysis is to look at time trends in mobile tariff prices, these yearly dummies are the variables of interest in this model. Specifically, if we want an estimate of how much price p_{iot} changes over time, holding everything else constant (i.e. controlling for tariff characteristics and the operator), then this is equivalent to the hedonic price $(\partial p_{iot})/(\partial \text{Time}_t) = \beta_t$. In our model, we include dummy variables for the years 2014, 2015, 2016 and 2017. The coefficient (β_t) for each variable represents, therefore, the change in the average monthly price in each given year relative to 2013, controlling for the tariff's characteristics and the operator.
- 3.17 *Operator* is a vector of dummy variables for each mobile network operator. The specification includes a total of O operator dummies with o representing each individual operator. If we want an estimate of how much price p_{iot} changes by operator, holding everything else constant, then this is equivalent to the hedonic price $(\partial p_{it})/(\partial \text{Operator}_o) = \gamma_o$. In our model, we include dummy variables for Vodafone, EE, O2 and MVNOs. The coefficients (γ_o) for each operator dummy variable represent therefore the change in average monthly price by that operator in comparison to *Three*, controlling for the tariff's characteristics, handset quality and year.
- 3.18 Finally ε_{iot} is an error term or unobserved factors for each tariff observation i , associated with the operator o and a period of time t .²⁵

²⁵ We assume that the average values of the error term conditional on the observed quality variables and fixed effects is zero.

We perform a similar exercise to estimate differences in price trends between operators

3.19 To estimate differential trends across operators, we supplement the equation above as follows:

$$p_{iot} = \tau + \sum_{k=1}^K \alpha_k Q_{kiot} + \sum_{t=1}^T \sum_{o=1}^O \beta_{to} Time_t Operator_o + \varepsilon_{iot} \quad (3)$$

3.20 p_{iot} , Q_{kiot} , τ and ε_{iot} have the same definition and interpretation as above.

3.21 $Time_t Operator_o$ is a vector of dummy variables for each mobile operator (Three, Vodafone, EE, O2 and MVNOs) and year combination. The expected price change for an operator (e.g. EE) for a particular year (e.g. 2017), holding everything constant, is equivalent to the parameter $(\partial p_{iot}) / (\partial 2017 * EE) = \varphi_{EE2017}$. We have omitted the dummy combination of Three in 2013 so that all parameter estimates refer to the incremental impact of time to a specific operator in comparison to Three in 2013.²⁶

3.22 Using this specification we can also estimate the change in operators' prices between years, holding everything else constant. For example, for the estimated change in EE's prices between 2015 and 2017, this is equivalent to: $(\partial p_{iot}) / (\partial 2017 * EE) - (\partial p_{iot}) / (\partial 2015 * EE) = \varphi_{EE2017} - \varphi_{EE2015}$.

Hedonic analysis is straightforward to apply but is not above criticism and so care is required in using the technique

3.23 The hedonic pricing method is relatively straightforward to apply, because it is based on actual (or published) prices and product characteristics that are generally readily available. "Hedonics" is, however, not above criticism:

- a) Firstly, because the technique is based on actual prices and product characteristics available in the market over the period in question, the take-up of each tariff plan in the dataset is generally unknown²⁷. This means that we necessarily give each tariff equal weighting. In our first regression (equation 2) above, we also assume that all tariffs change in the same way over time.²⁸ How much this matters depends on (i) the nature of the dataset and the direction of price trends amongst individual tariffs; (ii) whether some tariffs are much more popular than others; and (iii) the interaction of these two factors. We discuss this in more detail in Sections 4 and 6.
- b) To separate price differences into those that are accounted for by quality differences and those that are accounted for by changing market conditions requires a thorough

²⁶ Since both operator and year are dummy variables, this methodology produces the same results as adding in operator and year dummies, and then introducing an interaction term between each operator and year.

²⁷ If take-up of each tariff plan were known one could estimate the hedonic pricing model using generalised least squares and weights determined by take-up.

²⁸ We have controlled for the fact that the impact of a specific operator may change over time in our second regression – equation 3 above. We have also tested the impact on our results of controlling for changes in the impact of data allowances over time and present these results as a sensitivity in Annex 3.

understanding of the quality characteristics that potentially drive price differentials. A risk with an econometric approach is that not all quality characteristics are captured. We discuss the factors which we have controlled for in Section 4. We also discuss the risk of not capturing all quality characteristics in Section 6, and the impact of not controlling for characteristics in Annex 3.

- c) The econometric approach generally assumes that the relationship between price and the product characteristics is linear-that prices change at the same rate when product characteristics change. Prices may however increase at an increasing or decreasing rate when product characteristics change. We discuss this in Section 6 and Annex 3.

4. Features of mobile plans and data sources

- 4.1 As discussed in the previous section, the hedonic pricing approach decomposes tariff plan differences into price differences that are accounted for by quality differences (i.e. handsets, inclusive data allowances) and those that are accounted for by changing market conditions (i.e. technology trends, operator-specific trends). To do this, we require a thorough understanding of the quality characteristics and market conditions that potentially drive price differentials.
- 4.2 In this section, we describe the characteristics of mobile offerings that we consider affect mobile prices and which we include in our hedonic regression analysis. We describe the data sources we have used and the data adjustments we have made.

Mobile prices are driven by a range of factors

- 4.3 The pricing strategies of MNOs are relatively complex compared to those of firms in many other industries. Operators vary their offerings along a number of lines in an attempt to capture as much of the heterogeneous tastes of consumers as possible; prices vary depending on the make-up of individual plans.
- 4.4 Some of the relevant features which we consider could have an effect on the prices of mobile plans are:
- a) **Contract Length.** Operators tend to charge lower prices for longer contracts to incentivise consumers to commit to staying with them for longer.
 - b) **Handsets.** A wide variety of different handset makes and models are made available by operators on their pay monthly plans. A common strategy for MNOs is to offer a handset upfront for free and recoup the cost of the device via a monthly charge, over the period of the contract. However, in the case of more expensive handsets, MNOs can also offer consumers the option of paying a one-off cost upfront and reducing the monthly payments accordingly. The better the quality of the handset, the higher the tariff price, all else equal.
 - c) **Inclusive allowances.** MNOs offer monthly allowances of texts, data and minutes as part of their tariff plans. These allowances are included as part of the mobile contract; the consumer only pays extra where they exceed the allowance. The total allowances and their mix vary between plans as MNOs attempt to shape their contracts to suit heterogeneous consumer demand. Larger allowances are typically associated with greater tariff prices, all else equal.
 - d) **Technology.** The service's technology can also affect the price that MNOs charge for a particular tariff. Consumers are likely to be willing to pay a premium for a tariff which offers a 4G service rather than a 3G service.
 - e) **Carphone Warehouse.** Carphone Warehouse typically sells mobile tariffs at a discount compared to those sold directly by MNOs.

- f) **Operator-specific factors.** The prices of mobile plans are also affected by factors which are specific to the individual MNO or MVNO offering them. For example, an operator may be able to charge higher prices across all of its tariffs where it has superior coverage, network quality, or customer service.
- g) **Timing.** The price of mobile plans can also be affected by timing issues. For example, there may be an event which takes place in a particular year which affects all mobile prices in that year, such as the release of a new technology.

4.5 The factors above can be included in our econometric analysis as either continuous or dummy variables. Continuous variables are those which can take any possible value such as the price variable. However, not all of the factors above can be controlled for using continuous variables. For example, whether a tariff is available in a certain year has only two possible options; yes or no. In these cases, we use dummy variables which take a binary value indicating whether or not an observation meets a certain criteria (for example, one if the tariff is present in 2013 and zero otherwise). In Annex 1, we discuss how we include these factors as variables in our econometric analysis.

4.6 Although we believe the factors listed above are the main determinants of mobile plan prices in the UK, a risk (as discussed in paragraph 3.23) is that there may be factors driving prices which we have not included in our analysis. We discuss the implications of this for our analysis in more detail in Section 6.

We collected data to control for the effect of these different factors on pricing

Our analysis focuses on post-pay tariffs

4.7 As discussed in Section 3, to estimate how prices that were available in the market over 2013 to 2017 have changed, we need to control for the effect of these factors on the prices of mobile plans by including them, as variables, in our hedonic regression. This requires us to collect data on each factor for the period 2013-2017.

4.8 For the analysis in this paper, we focused on collecting data for post-pay mobile plans including handsets. We also collected data for SIM-only plans. However, as discussed in Annex 1, we note that this dataset is incomplete²⁹ and therefore the results of our analysis based on this dataset are not robust.

4.9 We considered also collecting data for pre-pay plans but decided against this on the basis that the prices consumers pay each month for pre-pay plans depend on their specific usage in that month. Given that we do not have data on consumer usage of mobile services, we decided that inclusion of this data would not yield meaningful results. In addition, the trends in mobile plan take-up, as discussed at paragraph 2.1, suggest that post-pay plans are becoming relatively more popular than pre-pay plans over time.

²⁹ For example, the dataset is missing tariff data for giffgaff.

We collected data from two sources

- 4.10 For both types of plan, we collected publicly available data covering the tariffs, and associated handsets, of the major MNOs and MVNOs for the years 2013 to 2017.³⁰ In this section, for simplicity, we focus on the data we used for the analysis of post-pay tariffs with handsets and leave the discussion of SIM-only data for Annex 1.
- 4.11 The data we required to undertake the analysis for tariffs including handsets were not available from one individual source. We, therefore, had to use two data sources, from Strategy Analytics and Teligen, to form our overall consolidated dataset.
- 4.12 Strategy Analytics supplied us with weekly data on post-pay mobile tariff plans with a handset. This dataset included data on mobile handsets, including upfront prices, matched to tariff plans.³¹ However, the information on the characteristics of tariff plans (minutes, texts, data allowances) included in the Strategy Analytics dataset was incomplete across the five years so we needed to supplement this with information from a more complete dataset.
- 4.13 This information came from Teligen who provided us with comprehensive quarterly data on characteristics such as inclusive allowances, technology (3G or 4G)³², throttling and data overage charges³³. This dataset included no information on which mobile handsets were associated with those tariffs.
- 4.14 Strategy Analytics merged the datasets, matching the tariffs in the Teligen dataset to the handsets in the Strategy Analytics dataset.
- 4.15 This resulted in a dataset which included information on all of the factors discussed above from 2013 to 2017.³⁴

Teligen categorised handsets to allow us to control for handset quality over time

- 4.16 The large number of handset types available over the five-year period meant that the hedonic analysis would become unwieldy if they were each included as separate variables. Consequently, to make the analysis more manageable, Teligen grouped the handsets into

³⁰ For post-pay tariffs with handsets we collected data on the following operators: Three, O2, Vodafone, EE (including LifeMobile, T-Mobile and Orange), VirginMobile, TalkMobile and TescoMobile. The MVNO tariff data we have is incomplete as it does not include tariffs from all MVNOs. However, we do not consider this to be an issue since the focus of our analysis is prices set by MNOs. For SIM-only tariffs we collected data on the same operators excluding LifeMobile and TalkMobile.

³¹ We have adjusted prices for CPI using ONS published data.

³² Tariffs for EE, O2 and Vodafone have been classified on a case by case basis. Teligen used screenshots to confirm 4G connectivity for Three's tariffs. Tesco and VirginMobile did not classify different data plan types so the switch to 4G occurred for all plans at once. Teligen classified TalkMobile's tariffs based on the date of TalkMobile's switchover to 4G.

³³ Throttling refers to the intentional slowing of the internet service by the provider when a consumer consumes above a certain amount of data.

³⁴ The data were predominantly reported on a weekly basis with the exception of (some) unlimited minutes observations and mobile technology observations which were taken from the Teligen dataset and were collected quarterly. We consider this to be unproblematic since, according to Teligen, the non-price parameters of mobile tariffs do not change significantly between quarters.

one of three categories (basic, intermediate and advanced) to allow us to control for handset quality in our analysis.

- 4.17 The handset categorisations change over time to capture technological change in the mobile sector. Therefore, a certain handset may be considered ‘advanced’ in one year but could be categorised as ‘intermediate’ two years later if the technology has been superseded over that period.

In matching data from two sources a number of observations were dropped

- 4.18 In collecting data from two sources – see discussion above – a number of observations were dropped.
- 4.19 Observations were dropped for a number of reasons including:
- a) a close match could not be made between Strategy Analytics’ and Teligen’s data;
 - b) tariff observations were missing information on minutes, texts or data allowances;
 - c) tariffs observations were potentially duplicated;
 - d) tariffs included in the data were not of interest to this study (for example, business tariffs); or
 - e) inclusion of certain observations risked introducing multicollinearity into the analysis³⁵.
- 4.20 Having dropped these observations, the dataset for post-pay tariffs with handsets contains 1.3m observations which are broadly evenly distributed across five years. We consider this to be more comprehensive than the Frontier Economics dataset mentioned above as this dataset includes data on mobile technology (3G/4G).³⁶ We discuss the potential limitations associated with dropping data in Section 6.

Closer inspection of the dataset suggests that prices of plans with high data allowances behave differently from other plans

- 4.21 As discussed in Section 3, the hedonic technique relies on advertised prices and product characteristics which are made available in the market. It does not include tariffs which were discontinued before this period (which consumers may have remained on). Further, we do not have any data on consumer demand which allow us to appropriately weight our observations by actual consumer take-up in our analysis. We, therefore, give an equal

³⁵ Multicollinearity occurs when two or more explanatory variables are highly correlated and move in similar ways. Although multicollinearity does not affect the unbiasedness of the estimators, it can cause the estimated coefficients to become unstable. Tariffs which had a contract length of 36 months were only sold by Virgin Media and only in 2017. Therefore, including a dummy variable for 36 month contracts would have had introduced significant correlation between it and the Virgin Media and 2017 fixed effects. We, therefore, chose to drop these tariffs to avoid multicollinearity. Doing so only resulted in dropping 72 observations. We note that the mean variance inflation factor (VIF) in our dataset is estimated to be 2.52 (a VIF above 5 or 10 typically indicates multicollinearity to be a concern).

³⁶ The dataset that Frontier Economics used had 160,000 observations for the period 2014 to 2016 and did not control for mobile technology.

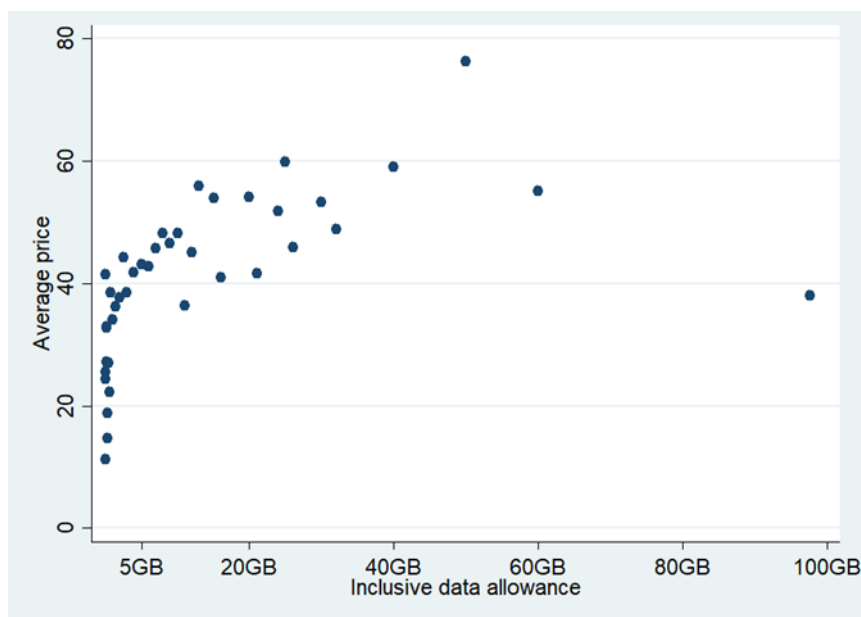
weighting to each tariff observation. Furthermore, when estimating average price changes over time, we also make the assumption that all tariffs evolve in the same way over time.³⁷

- 4.22 Given this, it is important for us to closely inspect the data to understand what the impact of these assumptions on our analysis might be. In particular, it is important to consider whether prices of different tariff bundles are moving together or in different directions over time, and whether some tariffs are more popular than others. This is because, if tariffs available in the market with particular characteristics behave differently than other tariffs and/or some tariffs are more popular than others, then actual price trends over time for consumers choosing to move or adopt new tariff plans could be different from the average that we estimate when including all tariffs in our analysis. This is something that we want to avoid in ensuring that the average price trends estimated in our analysis provide an accurate picture of price trends for consumers choosing to move or adopt new tariff plans in the UK mobile sector.
- 4.23 To evaluate our dataset on this basis, we undertook two inspections of the data. We concentrated on the relationship between data allowances and price for two reasons. As we expect inclusive data to be one of the major factors driving mobile tariffs, we consider that trends in mobile tariffs are more likely to be different at different levels of inclusive allowances than for the other variables. As our data variable is a continuous variable, this also provides for a wider range of cuts of the dataset based on the data variable.
- 4.24 Our first inspection of the data considered the average monthly price associated with different data allowances by year, as set out previously in Table 2.2. It is important to recognise that the analysis in this table shows the changes in the average prices of plans with the same data allowance for tariff plans that were available in the market over the period in question. It does not control for the fact that there are other characteristics which might influence prices other than data allowances (such as the handset chosen, length of the contract or the operators) that could be changing over time. Table 2.2 should, therefore, be considered as only broadly indicative of mobile pricing trends and does not provide a like-for-like comparison – see discussion in paragraphs 2.3 to 2.9.
- 4.25 Table 2.2 indicates that, for most tariffs with a certain inclusive data allowance that were available in the market between 2013 and 2017, the average price has been falling over time between 2013 and 2017. The general exception to this is for tariffs with data allowances greater than 20GB per month, which appear to be increasing in price. This may, therefore, suggest that the relationship between data allowance and price is different for tariffs with extremely high data allowances compared to those with low allowances.
- 4.26 To complement this, we also considered Figure 4.1, below. This shows the average prices of mobile plans with different levels of inclusive data allowances at all points in time. The same caveat as above should apply here since the values do not account for quality characteristics of tariffs other than data allowances.

³⁷ See footnote 28.

4.27 Inspection of Figure 4.1 appears to show that average prices of mobile contracts that were available in the market between 2013 and 2017 increase with the level of data allowance reasonably in proportion to the increase in data allowance up until the allowance reaches 20GB per month. Above this level, the relationship appears to change. Again, this may indicate therefore that there may be a different relationship between price and data allowance for tariffs with very high data allowances, compared to all others.

Figure 4.1: Average monthly price by inclusive data allowance (for all years)³⁸



Observations with data allowances greater than 20GB per month have been dropped

4.28 In light of the indicative evidence above, we were concerned that the inclusion of tariff plans with large data allowances would lead to results which may be sensitive to different variations in the data points included in our analysis, and so would not provide us with robust price trends. To overcome this potential issue, we therefore took the decision to drop observations from the analysis where the inclusive monthly data allowance was greater than 20GB. Our choice of which observations to exclude to promote stability of our results was not straightforward.

4.29 We chose a threshold of 20GB to maximise the number of observations we included in the analysis while reducing the instability issues. In Annex 3, we present sensitivity tests which show that the choice of threshold has no significant effect on our findings. In excluding tariff plans where the inclusive monthly data allowance was greater than 20GB, this provides us with a final consolidated dataset of 1.2 million observations.

4.30 We recognise that in dropping these observations, this reduces the scope of our analysis. This would be particularly problematic if the majority of consumers purchased tariffs with

³⁸ We note that a similar trend is shown when Figure 4.1 is plotted separately for each year and operator.

data allowances in excess of 20GB per month between 2013 and 2017 since our analysis would not be representative of the prices that many consumers actually pay. We have no consumer demand information, so we do not know the exact proportion of consumers which purchased tariffs with high data allowances in the time period studied. However, analysis from our Connected Nations report shows that average data usage per person in 2017 was 1.9GB, indicating that many consumers do not require data allowances in excess of 20GB per month³⁹. This may suggest that our decision to exclude tariffs with higher data allowances is unlikely to mean that the dataset used in our analysis is unrepresentative of the prices available to the wider population.

4.31 However, as a sensitivity test, we also ran the analysis for the full set of observations, including all tariffs with high data allowances. The detailed results for the full set of observations are presented in Annex 2. Although the magnitude of average prices in each year changed when doing so, the overall downward price trend remained the same⁴⁰. This gives us reassurance that our approach to dropping these observations does not markedly change our main findings.

³⁹ Source: [Ofcom Connected Nations Report, 2017](#), paragraph 3.8 and [Ofcom Connected Nations Report, 2016](#), Figure 23.

⁴⁰ Based on the full set of observations we estimate that the average price of post-pay tariffs with handsets declined by £4 (in comparison to a decline of £6 based on tariffs with inclusive data allowances less than or equal to 20GB). Although not robust, we have also estimated results for tariffs with inclusive data allowances above 20GB and the results suggest that prices have been increasing on average for these tariffs.

5. Results

- 5.1 In this section we present the main results of our analysis. Specifically we discuss our key results using available post-pay plans with handsets for tariffs with inclusive data allowances less than or equal to 20GB.⁴¹
- 5.2 In this section we also discuss the approach we have adopted to estimate the hedonic regression and the functional forms used in our analysis.

We use a pooled OLS, following a general-to-specific procedure to compare prices on a like-for-like basis

- 5.3 As set out in the previous section, as our analysis is focused on available plans with inclusive data allowances less than or equal to 20GB per month, the consolidated final dataset for post-pay tariffs with handsets comprises of 1.2 million observations across five years.
- 5.4 We do not have data for all tariff plans in all periods as mobile operators typically change the characteristics of their available tariffs (and associated handsets) over time. The effect of this is that we have an unbalanced panel⁴², which means that it is not distinct from a pooled cross-sectional analysis.
- 5.5 A pure fixed effects estimation would not be an appropriate technique because it would not be able to take account of within-observation variation over time. Given this, we run a pooled OLS using a general-to-specific procedure, controlling for operator and year fixed effects.⁴³

The relationship between price and quality is not linear so we test a range of functional forms

- 5.6 As set out in Section 3, a key consideration with hedonic analysis is that the relationship between price and the quality characteristics of the product may not be linear – prices may change at an increasing or decreasing rate when product characteristics change. On the basis of a test for selecting the most appropriate functional form, we estimate our results using two functional forms:

⁴¹ We have also estimated the yearly change in the prices of mobile tariffs based on SIM-only tariffs available in the market over the period in question. Our results for SIM-only are consistent with our analysis of tariffs with handsets as well as Frontier Economics' SIM-only analysis – see Annex 2 for a discussion. However, we have less confidence in the SIM-only analysis since it is based on a more limited dataset.

⁴² It is an unbalanced panel because post-pay plans and handsets are not always present throughout the five years of study – observations are, therefore, often not available in all time periods. For example, the number of 3G tariffs available dropped off rapidly in 2015/16.

⁴³ This approach starts with a general statistical model that captures the essential characteristics of the underlying dataset. The general model is reduced in complexity by eliminating statistically insignificant variables, checking the validity of the reductions at every stage to ensure congruence of the finally selected model. This ensures that all contributing variables are included in the final model. We note that in this case the results of the general and specific regression are the same.

- i) a functional form strictly based on the results from the Box-Cox test of functional form; and
- ii) a linear-log function, where a log transformation is applied to the data allowance variable. This choice is informed by the results of the Box-Cox test but is easier to interpret.

5.7 We note that using these two different functional forms does not significantly change our results. However, we have chosen to estimate our results based on these two functional forms, because they allow us to obtain lower and upper bounds for our price trends. We discuss functional form issues in more detail in Annex 3.

Our results are consistent with what we would expect pre-estimation and are robust to a number of alternative specifications

5.8 As discussed in Section 4, our inspection of the data suggests that plans with data allowances greater than 20GB behave differently from other plans. As such, we have limited our hedonic analysis to plans with handsets with data allowances less than or equal to 20GB. As discussed in paragraphs 4.30 and 6.6, we do not expect this to bias our results as the majority of consumers are expected to purchase tariffs with data allowances less than or equal to 20GB⁴⁴.

5.9 The full list of results for all variables in the specification is reported in Annex 2 (Table A2.1), alongside a discussion of our interpretation of these results. The results are broadly consistent with what we would expect pre-estimation. For example, they can be interpreted as showing that, on average:

- a) prices are higher, the better quality handset associated with the plan;
- b) longer plans are associated with lower prices;
- c) prices are higher the larger the bundle of minutes, texts and data in the plan; and
- d) tariffs retailed by Carphone Warehouse tend to be cheaper.

5.10 We note that the impact of 4G technology on the prices of post-pay plans is close to zero. As we discuss in Annex 2, this may be driven by a number of factors including the impact of the time trend.

5.11 As set out in Annex 3, we have also checked how sensitive our results are to a number of changes. The results in Table A2.1 are robust to these. The changes we have tested include:

- i) controlling for inclusive minutes and SMS allowances using continuous rather than dummy variables.

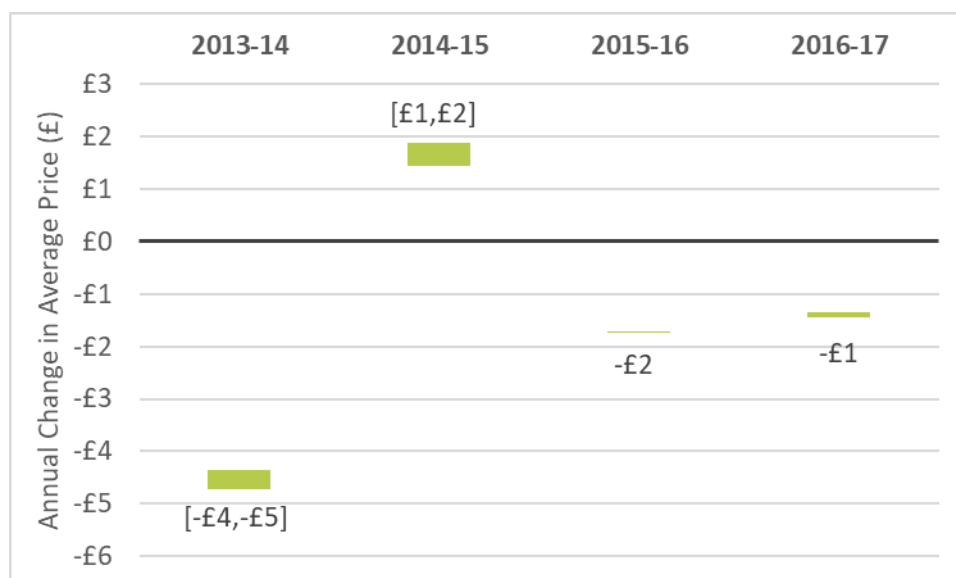
⁴⁴ However, as a sensitivity test, we also ran the analysis for the full set of observations, including all tariffs with high data allowances – see Annex 2. The overall downward price trend remained the same.

- ii) controlling for inclusive data allowances using a dummy rather than a continuous variable.
- iii) controlling for contract length using a continuous variable rather than dummy variables.
- iv) controlling for MVNOs using controls for individual MVNOs rather than a group MVNO control and dropping MVNO tariffs from our dataset.
- v) controlling for the impact on price of data allowances changing over time.
- vi) controlling for other potential variables (throttling, tethering, SMS prices) to impact price.
- vii) testing how sensitive our results are when alternative data thresholds (15GB and 25GB rather than 20GB) are used in the analysis.
- viii) comparing our main results to the estimated weighted average price trends from our second specification.
- ix) dropping tariffs retailed by Carphone Warehouse.

We estimate that the monthly prices of available post-pay plans with handsets (and data allowances less than or equal to 20GB) fell by £6 between 2013 and 2017

5.12 On the basis of the detailed results in Annex 2, Figure 5.1 illustrates the lower and upper bound of the estimated yearly change in monthly prices since 2013.

Figure 5.1: UK mobile price trends for available post-pay plans including handsets for each year



5.13 Our analysis indicates that the prices of post-pay plans with handsets with monthly data allowances less than or equal to 20GB available between 2013 and 2017 have fallen over time. Specifically, we estimate that, on average, the monthly prices of these tariffs have

declined by £6 between 2013 and 2017 in real terms (deflated using CPI), once we control for other factors (as set out in paragraph 4.4).⁴⁵

- 5.14 Given that our Connected Nations research suggests that average monthly data usage per person in 2017 was estimated to be 1.9GB – see paragraph 4.30 above, indicating that many consumers do not require data allowances in excess of 20GB per month. This implies that our results for tariffs with data allowances less than or equal to 20GB are likely to apply to the majority of mobile consumers choosing to move or adopt new tariff plans. In other words, the average trend in prices for consumers choosing to move or adopt new tariff plans during this period is likely to be close to the trend presented in Figure 5.1.
- 5.15 This finding suggests that, on average, for mobile consumers choosing to move or adopt new tariff plans, they are getting better value for money over time, all else being equal. That is, they are either able to:
- a) buy tariffs with the same quality characteristics as before at lower prices; or
 - b) buy tariffs with improved quality characteristics at prices which have not increased in proportion to the increase in quality (for example, paying twice as much money for tariffs with data allowances which are three times greater than before).
- 5.16 Despite this, we would be concerned if consumers were getting more for more over time (example b), above) without having the option of remaining on lower value tariffs if they prefer. Analysis of our underlying dataset indicates that lower value tariffs remain available for consumers who demand them, so we are confident that consumers who prefer to remain on cheaper tariffs with basic characteristics are not being made significantly worse off over time.⁴⁶
- 5.17 In general, though, consumers are demanding better quality packages over time. For example, the average volume of data consumed per subscriber per month was 1.9GB in 2017, up from 0.4GB in 2013.⁴⁷ We, therefore, consider that given that prices are continuing to fall overall over the period, and consumers are not forcibly being migrated in a way that reduces welfare, the mobile sector is continuing to work in favour of consumers with respect to available tariffs for consumers choosing to move or adopt new tariff plans.
- 5.18 We recognize, however, that there are multiple indicators of competitiveness, and so this analysis should not be viewed in isolation. In particular, our analysis does not include tariffs which were discontinued before this period (which consumers may have remained on) and

⁴⁵ We note that between 2014 and 2015 we see prices increase. This is consistent with our statement in the [Ofcom PSSR Consultation](#), where we found that the minimum prices for contracts including handsets increased by 12% between 2014 and 2015 (Figure A7.15, 2016). In that analysis, we suggested that the increase could be explained by an increase in the price of premium handsets or the additional cost of 4G packages. Although we have controlled for handset quality and mobile technology in our regression, it is possible that the entire effect is not picked up by these variables. This may be partly driven by the handset categorisation, as discussed in Section 6.

⁴⁶ Although low-value tariff users may be somewhat worse off from having fewer low-value tariffs to choose between.

⁴⁷ Source: [Ofcom Connected Nations Report, 2017](#), paragraph 3.8 and [Ofcom Connected Nations Report, 2016](#), Figure 23.

so it does not speak to broader consumer welfare questions (for example, consumers continuing to pay handset repayments although they are out-of-contract).

We estimate differences in price trends between operators

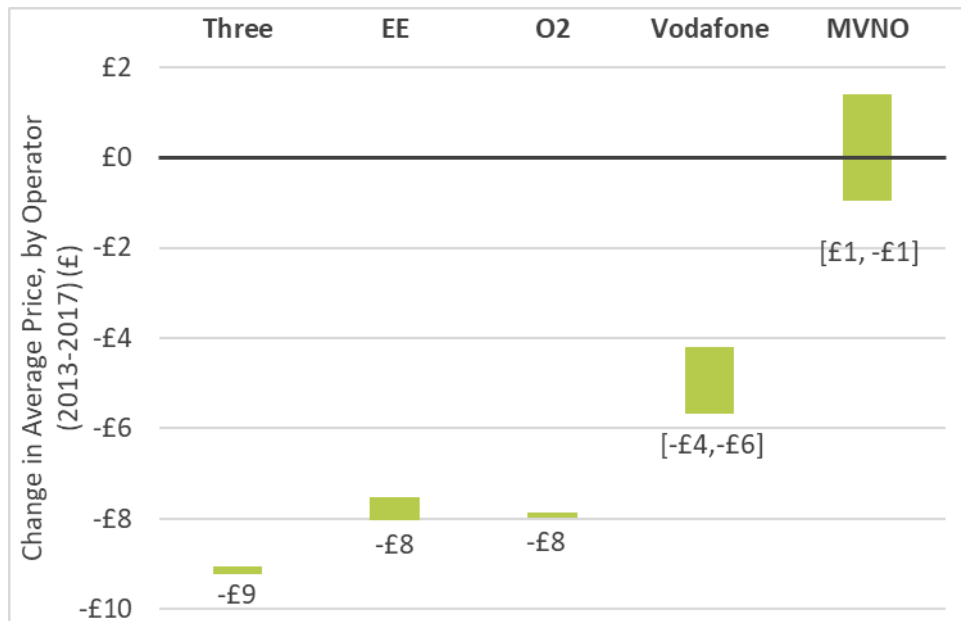
- 5.19 The results above estimate the price trends of available post-pay plans with handsets (and data allowances less than or equal to 20GB) between 2013 and 2017. As discussed in Section 3, we have also estimated a version of our main regression which presents a more granular picture of operators' pricing trends⁴⁸. In particular, this regression allows us to estimate the effect on price of each operator by year (e.g. Three's effect on price in 2015) while controlling for changes in the other quality characteristics. In this section we present the main results of this analysis.
- 5.20 As above, our analysis is based on available post-pay tariff plans with handsets and inclusive data allowances less than or equal to 20GB.
- 5.21 The full list of results for this specification is reported in Annex 2 (Table A2.2), alongside a discussion of our interpretation of these results. We focus in this section on the estimated price trends by operator and note that the results for the other variables are broadly consistent with those discussed above at paragraphs 5.9-5.10. The results in Table A2.2 are also robust to the alternative specifications outlined at paragraph 5.11.⁴⁹
- 5.22 On the basis of the detailed results in Annex 2, Figure 5.2 illustrates the lower and upper bound of the estimated change in monthly prices between 2013 and 2017 by operator.⁵⁰

⁴⁸ We have chosen not to present this regression as our main specification as we are mainly interested in pricing trends over time. Using this regression as our main specification would require us to rely on weighted average effects in order to estimate the unique effect of each year on price. As a robustness check we have calculated these weighted average effects and note that the results are consistent with our main specification. This analysis is presented in Annex 3.

⁴⁹ For conciseness we do not present the robustness checks for this modified specification in Annex 3.

⁵⁰ The lower and upper bound takes into account our choice of functional form (Box-Cox and linear-log).

Figure 5.2: UK mobile price trends for available post-pay plans including handsets for 2013-2017, by operator



- 5.23 Our results based on this regression suggest that there are significant differences in price trends between mobile operators. As discussed in Annex 3, we have estimated a range for each operator using two functional forms. Three’s available tariffs during the period have become significantly more competitive over the period, whereas prices for tariff plans available in the market during 2013 and 2017 for O2, EE and Vodafone have declined more slowly, all else equal. The results are mixed for MVNOs. Based on our main functional form (Box-Cox), presented as the lower bound of the range below (-£1), we estimate that MVNOs’ prices for tariffs plans available between 2013 and 2017 have on average reduced. As discussed in Annex 3, we consider the Box-Cox to be our main functional form as it estimates which non-linear transformation fits the data best.
- 5.24 As above, this finding suggests that consumers are getting more for more over time across the MNOs although the rate of change has varied.

6. Potential limitations

- 6.1 As discussed above in Section 3, while the hedonic pricing method is relatively straightforward to apply, it is not above criticism. Hedonic pricing analysis is driven by data availability and therefore has some limitations. In the interest of academic robustness and transparency we discuss these in this section. In particular, we consider the following:
- a) Data limitations
 - b) Inclusion of mobile handset data
 - c) Potential for endogeneity

Data limitations

- 6.2 Our analysis is limited by the availability of appropriate data. In particular:
- a) **Lack of demand information** - all tariffs are given equal weighting, instead of weighting by demand.
 - b) **Data on over-use charges** - additional data would allow us to control for the overage charge associated with tariffs.
 - c) **Dropping of observations** – we necessarily dropped a number of observations from our final dataset.
 - d) **Double-counting of observations**- Due to the data collection process, a number of SIM-only tariffs have been double-counted.

Lack of demand information

- 6.3 As discussed in Section 3, our dataset is comprised of the publicly available prices of mobile firms rather than the tariffs consumers actually purchase. This is a necessity since data on consumer usage are not readily available to us and we do not know the take-up of each plan in our dataset. We therefore necessarily give each tariff equal weighting in our analysis.⁵¹
- 6.4 The extent to which this lack of demand data may impact on our analysis depends on a number of factors:
- a) the direction of price trends amongst individual tariffs;
 - b) whether some tariffs are more popular than others; and
 - c) the interaction of (a) and (b).

⁵¹ We note that our dataset therefore excludes tariffs which have been negotiated by mobile customers.

Direction of price trends amongst individual tariffs

6.5 In Section 4, we described how our inspection of the data suggested that tariff plans with inclusive data allowances greater than 20GB per month behaved differently to those with smaller data allowances. We therefore focused our analysis on tariff plans with inclusive data allowances less than or equal to 20GB. In theory, by omitting tariffs with data allowances greater than 20GB, our results will no longer be representative of the average price available to consumers. If, for example, the prices of tariffs with larger inclusive data allowances have declined more slowly than the prices of tariffs with smaller inclusive data allowances, our results may overestimate the true average price decline.

Demand for tariffs

6.6 However, as outlined in paragraph 6.4, the extent to which this impacts our analysis also depends on whether tariffs with inclusive data allowances greater than 20GB are relatively popular compared to tariffs with smaller inclusive data allowances. As discussed in paragraph 4.30, we consider that omitting tariffs with data allowances greater than 20GB does not bias our results since we expect that most consumers bought tariffs with data allowances lower than 20GB per month between 2013 and 2017. Our estimated price trend should, therefore, be close to the average prices available to consumers.

6.7 We note in Section 4 that although the data suggests that a data allowance of 20GB is a natural threshold for excluding observations, it is a subjective decision. In Annex 3, we conduct robustness checks which test the effect of varying the threshold, noting that it does not have a significant effect on our results. As we give all tariffs equal weight in our analysis, assuming the tariffs within these alternative thresholds are not significantly more popular than those with data allowances less than or equal to 20GB, our results can therefore be considered indicative of the average price trend for those alternative thresholds.

Interaction between price trends and demand for tariffs

6.8 As outlined in Table 2.2, the prices of post-pay plans with inclusive data allowances less than or equal to 20G behave similarly over time. However, we recognise that our lack of consumer demand information may still produce potential issues for our analysis. In particular, we consider that there could be an issue if consumer demand evolved over the period of our analysis. We recognise that, over time, consumers have increased their mobile data usage and, therefore, expect that they may hold a stronger preference for tariffs with larger inclusive data allowances in the later years of our dataset.

6.9 Since all of the observations in our dataset are given equal weight, our analysis will only reflect this change in preferences if the number of available tariffs with certain data allowances adjusts with consumer preferences over time. If this is not the case, our analysis runs the risk of putting too much weight on tariffs with smaller inclusive data allowances in later years.

6.10 We consider that our dataset is broadly likely to evolve with consumer preferences in this way, as operators tailor their available tariffs to meet consumer demand. As discussed in paragraph 5.16, analysis of our dataset suggests that while lower value tariffs do remain available, the number of available tariffs with larger data allowances has risen. To illustrate this, Table 6.1 shows the proportion of tariffs available in each year with a given data allowance.

Table 6.1: Proportion of tariffs available with a given data allowance by year⁵²

	2013	2015	2017
1GB data allowance	20%	17%	14%
5GB data allowance	2%	7%	7%
20GB data allowance	1%	6%	8%

6.11 This gives us a degree of confidence that, in the absence of demand information, giving equal weight to observations in the analysis is a reasonable approach as operators appear to adjust their available tariffs to meet changing market demand.

6.12 To summarize, different price trends across tariffs, differences in consumer demand for particular tariffs, and the interaction of these two effects can lead to estimated average price trends which are not representative of those experienced by consumers choosing to move or adopt new tariff plans. We do not consider these effects to be an issue for our dataset. This is because evidence from our Connected Nations report (discussed at paragraph 4.30) suggests that demand for tariffs with inclusive data allowances above 20GB is likely to be low, and that the direction of price trends across tariffs with data allowances less than or equal to 20GB are broadly similar.

Over-use charges

6.13 Consumers who exceed their inclusive allowances will be subject to over-use, or overage, charges. One potential strategy of mobile operators may be to include relatively limited allowances and rely on overage charges to drive their revenues.

6.14 This could be relevant to our analysis as it is a factor which potentially affects the price consumers pay for their mobile service. If prices paid for overage charges change over time, it could have an impact on our trend analysis and, therefore, excluding overage charges may mean that our analysis is not capturing the full prices that consumers pay over time.

6.15 However, we are unable to control for the impact of overage charges in our analysis for two reasons:

⁵² The percentages in this table do not sum to 100% as there are a range of other data allowances (such as 4GB) associated with the tariffs in the dataset.

- a) Our dataset is missing a considerable proportion of data on the overage prices that operators charge; and
 - b) Understanding the overage charges that consumers actually pay depends on us having information on the extent to which consumers exceed their monthly allowances. We do not have access to this information.
- 6.16 Excluding overage charges from our analysis, therefore, means that we likely underestimate prices that consumers actually pay for their mobile services. More importantly for our trend analysis, if the level of overage charges changes significantly over time, and is not captured in our analysis, we will not be able to estimate an accurate trend.
- 6.17 We consider the impact of excluding this from our analysis to be reasonably limited. Consumers, in general, tailor their plans to their expected usage, particularly if there is a prospect of substantial over-use charges. Where they initially underestimate their expected consumption, most operators will offer them the option to upgrade their contracts to ones with increased allowances (as this would offer them more certainty over future cashflows). We have no reason to believe that this has varied over the five year period of our analysis and so should not affect our trends.

Dropping of observations

- 6.18 As discussed in Section 4 and above, we have dropped tariffs with inclusive data allowances greater than 20GB from our dataset as those tariffs behaved differently to tariffs with inclusive data allowances less than or equal to 20GB. We discuss the impact of this on our results in Annex 2.
- 6.19 As also discussed in Section 4, in the process of matching datasets, we dropped a number of observations.
- 6.20 In theory, dropping observations could bias our results if it is not done randomly. Therefore, we carried out two statistical tests to test whether the observations we had dropped had been dropped randomly.⁵³
- 6.21 The tests suggest that observations had been dropped randomly for the years 2013, 2015 and 2016. For 2014, one test suggests that the dropped observations were randomly distributed but the other rejects this.⁵⁴ Both tests suggest that the observations were not randomly dropped for 2017. This may suggest that dropping observations from 2014 and 2017 may introduce some bias into our results. However, we would expect any bias caused by the dropped observations to be reasonably limited as they make up a small proportion of the overall dataset (3%).

⁵³ A mean difference F-test (one way analysis of variance – ANOVA) and Bartlett’s chi-squared test for equal variances.

⁵⁴ The ANOVA test suggests that the observations have not been dropped randomly for 2014, although the results of the Bartlett’s test suggest that they have.

Inclusion of mobile handset data

- 6.22 The main analysis in this paper includes data of the mobile handsets that were included in tariff plans available during 2013 to 2017 and the prices paid by consumers for them.⁵⁵ Studies of mobile prices have previously tended to ignore the cost of mobile handsets in their analysis either because of a lack of available data or because it was considered that excluding handset costs meant that ‘pure’ pricing strategies could be distinguished from changes in the prices of handsets.⁵⁶ However, we have chosen to include handsets as we consider them likely to be a key determinant of a mobile operator’s pricing decision.
- 6.23 We recognise that recently, SIM-only contracts have become more popular, so we have also included analysis of this side of the market. As discussed in Annex 2, our findings for SIM-only plans and those with handsets are consistent with each other, indicating that our analysis of available plans with handsets is not driven solely by the prices of handsets. However, as we discuss in paragraphs A1.6 and A1.7, our results for SIM-only are not robust as the dataset is incomplete.
- 6.24 In including mobile handsets in our analysis, Teligen has sorted them into three quality categories. We appreciate that doing so means that we do not completely control for differences in handsets if there is substantial variation in handset quality within categories. Ideally, we would include a robustness test whereby quality is accounted for in different ways but are unable to do so given a lack of alternative options.

Potential for endogeneity

- 6.25 A common issue in econometric analysis is that it is difficult to specify an equation which includes every possible explanatory variable. If there are important omitted variables which are correlated with the included independent variables, then the estimated coefficients of these variables will, in part, capture the impact of the omitted variables. In this case, the estimated coefficients would be biased. In general, the magnitude and direction of the bias depend on the correlation between the omitted and included variables.
- 6.26 Although we consider that we have included all the important explanatory variables in our estimation, possible omitted explanatory variables include:
- a) Complementary features;
 - b) Variables to control for the impact of quality features on price changing over time; and
 - c) The level of competition.

⁵⁵ It does not include tariffs which were discontinued before this period (which consumers may have remained on). As such, it does not speak to broader consumer welfare questions (for example, consumers continuing to pay handset repayments although they are out-of-contract, etc).

⁵⁶ For example, see [Evaluating market consolidation in mobile communications; Genakos, Valletti and Verboven \(2015\)](#), and [Annex 21 to H3G's response to the PSSR Consultation; Frontier Economics \(2017\)](#).

Complementary features

- 6.27 Some plans may include watching Netflix not counting towards a customer's data allowance and time-limited free access to some services (e.g. Apple Music). If these factors were significant determinants of mobile operators' pricing decisions, and their importance varied across the years, they may affect our estimated pricing trends.
- 6.28 We are unable to include these in our analysis due to a lack of data and since they are of a qualitative nature and are difficult to assign a value to. However we note that consumer survey evidence suggests that only a small proportion of mobile consumers take "added extras" into consideration when taking out their mobile contracts.⁵⁷ We therefore do not consider that omitting these variables will have a significant effect on our results.⁵⁸

Controlling for the impact of quality features changing over time

- 6.29 An additional possible criticism of our analysis is that our specification assumes that the relationship between the quality characteristics and price is constant over time. However, this may not be the case. For example, one extra GB of data allowance may have a different effect on price in 2013 than in 2017. Omitting a variable which controls for this relationship from our analysis runs the risk of biasing our results and, therefore, inaccurately reporting pricing trends.
- 6.30 We could control for the potential relationship by including variables which interacted the quality characteristics and time variables. However, we have chosen not to include these variables in our main specification since doing so would potentially introduce significant collinearity into the analysis and would not allow us to use the Box-Cox test of the appropriate functional form.⁵⁹
- 6.31 In Annex 3, we test the inclusion of these interaction terms using a logarithmic transformation of the continuous explanatory variables. Although we cannot be sure that this transformation is appropriate (given that we cannot use the Box-Cox test in this instance), we note that the trend implied by these results is consistent with that of our main specification. This gives us confidence that the omission of variables which interact data and time does not bias our results.

⁵⁷ When asked what factors they considered when taking their mobile phone deal, only 13% of consumers said they had considered what "added extras" would be included. We note that added extras may include complementary features as well as other factors. Source: [Ofcom Consumer Engagement Quantitative Research](#), 2018. Q42. Base: All responding about their mobile who are in contract for their service, including those on a SIM-only deal.

⁵⁸ We note that, to the extent that consumers do pay attention to these features, they may affect the time and operator dummies as these features are not offered in all time periods by all operators.

⁵⁹ This is because the Box-Cox test of functional form cannot simultaneously estimate the optimal transformation for single-variable predictors and for interaction terms that depend on them.

Level of competition

- 6.32 In theory, changes in the level of competition in the market might also be a factor which affects mobile prices. As the focus of this paper is to estimate price trends (controlling for tariff characteristics) rather than determine the factors driving price changes over time, we do not consider it necessary to control for changes in the level of competition.
- 6.33 However, we consider that the competitive intensity of the UK market has remained reasonably stable over the period of our analysis for two reasons: between 2013 and 2017 the number of MNOs remained unchanged and our measure of market concentration remained relatively stable.^{60 61} We therefore would not expect controlling for changes in the level of competition to significantly affect our results.

⁶⁰ The Herfindahl-Hirschman Index (HHI) index is estimated by taking the absolute value of the market share of each firm in the industry and then squaring this number. This number can range from close to zero (a very large number of small firms) to 10,000 for a market with one operator with 100% market share.

⁶¹ Source: [Award of the 2.3 and 3.4 GHz spectrum bands](#), 2017, Figure A1.9.

A1. Specifying variables in our analysis

Data can be specified as either continuous or dummy variables

- A1.1 As discussed in Section 4, we consider that a number of factors have an impact on the pricing of available mobile tariffs. In this annex, we present how these variables are specified in our analysis.
- A1.2 As set out in Section 4, not all of the factors can be controlled for using continuous variables. In these cases, we use dummy variables which take a binary value indicating whether or not an observation meets a certain criteria.
- A1.3 In our base model specification, we have included our dependent variable, price, and the data allowance explanatory variable as continuous variables. Everything else is specified as a dummy variable. Table A1.1 sets out, in detail, the main variables we have included in our main specification and sets out our reasoning for whether the variable is included as a continuous or dummy variable.

Table A1.1: Specification of dependent variable and quality characteristics

Variable	Specification
Price	<p>Average monthly price is the dependent variable in the analysis and enters the econometric model as a continuous variable. It is calculated by dividing the one-off handset charge (where it is non-zero) and any connection fee by the number of months in the contract and adding it to the monthly charge.⁶²</p> <p>Price is expressed in real terms as we have deflated the price measure using CPI data published by the ONS.</p>
Mobile handset	<p>As discussed in paragraphs 4.16-4.17, Teligen categorised each handset into three categories for each year, defined as basic, intermediate and advanced. We have created a dummy variable for each category to allow for different handset technologies. We discuss the limitations of this approach in Section 6.</p>
Contract Length	<p>Contracts in our dataset have a limited number of lengths (12, 18 and 24 months) and so we control for this variable using dummy variables. Using dummy variables instead of continuous values is preferable in this instance as it allows us to estimate the effect associated with each contract length separately. We test the robustness of this approach in Annex 3.</p>

⁶² We focus on published mobile tariffs. Other analyses have taken different approaches to measuring price, such as baskets to represent popular plans, estimating price per unit of mobile output and Average Revenue Per User (ARPU).

Data allowances	<p>We include data allowances in the analysis as a continuous variable for the reasons set out in Annex 3. We include a robustness test in Annex 3, which considers the effect of, instead, using dummy variables to represent data allowances.</p> <p>As we discuss in Section 4, we exclude tariffs with data allowances in excess of 20GB per month.</p>
Minutes allowances	<p>46% of observations in the combined dataset have unlimited minutes (to be used across either off-net or on-net calls⁶³) and the remaining tariffs have limited minutes allowances. We use a dummy variable to allow for this which takes a value of one if the tariff has unlimited minutes and zero otherwise.</p>
Texts allowances	<p>78% of observations in our dataset have unlimited texts. We control for text allowances by using a dummy variable which takes a value of one if the tariff has unlimited text allowances and zero otherwise.</p>
Technology	<p>If consumers sufficiently value mobile speeds, they may be expected, or willing, to pay extra to subscribe to a service of superior quality. We use a dummy variable to allow for this which takes a value of one if the tariff is 4G and zero otherwise.</p>
Carphone Warehouse	<p>Tariffs retailed through Carphone Warehouse are typically lower priced than those retailed directly by the mobile network operators. We include a dummy variable that takes a value of one if the tariff is not sold by Carphone Warehouse and zero otherwise.</p>
Operator	<p>We include dummy variables for Vodafone, EE and O2. These operator-specific dummy variables take a value of one if the observation is associated with a particular MNO or zero otherwise. They are used to control for differences accounted for by mobile operators that can affect prices. For example, these could be whether certain firms have different coverage, as discussed at paragraph 4.4 (f).⁶⁴</p> <p>We also include a variable which controls for the impact that MVNOs have on mobile prices. Unlike for the case of MNOs, we did not specify individual variables for each MVNO. We made this decision for two reasons. Firstly, because we have less interest in</p>

⁶³In some cases, our dataset does not distinguish between on-net and off-net SMS and minutes allowances. We, therefore, do not have sufficient data to create variables which control for each of these options. Instead, we have included a variable which captures the total number of SMS/minutes included in a tariff plan. We do not expect this to have a significant impact on our results since SMS and minutes allowances are not large drivers of our results and we consider consumers to pay more attention to the total number of inclusive texts/minutes in a plan as opposed to the split between on and off-net.

⁶⁴ We have included tariffs sold by T-Mobile, LifeMobile and Orange in our EE dummy variable.

the effect of individual MVNOs on pricing and, secondly, because we are not confident that we have a full dataset for all MVNOs so any results we get for individual MVNOs may not be representative.

Instead, we have aggregated the observations for MVNOs into one MVNO dummy variable which takes a value of one if the observation is associated with any MVNO or zero otherwise. In Annex 3, we run a sensitivity where we include MVNOs as separate variables, noting that this does not significantly affect the results.

Year

We include dummy variables for the years 2014, 2015, 2016 and 2017. These year-specific dummy variables take a value of one if the observation falls in that year or zero otherwise. These are used to control for in-year shocks that could affect the price of mobile tariffs and to estimate the trend in prices over time after controlling for changes in the tariff's characteristics, handset quality and operator. For example, these could include a new technology release in a certain year, as discussed at paragraph 4.4 (g).

- A1.4 As discussed in Section 3, to estimate price trends by operator in our second specification we include a vector of dummy variables for each mobile operator (Three, Vodafone, EE, O2 and MVNOs) and year combination. This replaces the individual operator and year dummy variables in our base regression.

SIM-only data collection was more straightforward

- A1.5 Teligen also provided us with a separate dataset for SIM-only tariffs. This dataset includes, for each available pricing plan, information on the monthly contract price (including any offers), monthly minutes, texts and data allowances, mobile technology and contract length. We did not require any information from Strategy Analytics since SIM-only tariffs do not include a handset.
- A1.6 This dataset includes 1,456 observations between 2013 and 2017 which are also broadly distributed across the years. It includes observations for most mobile operators which offer SIM-only plans but does exclude some notable ones, such as giffgaff.⁶⁵
- A1.7 We have specified variables in the same way for our analysis of SIM-only contracts as we did for tariffs with a handset. We do not put as much weight on the analysis undertaken

⁶⁵ Due to the data collection process, it could be argued that a number of SIM-only tariffs have been double-counted. Specifically, in some cases, where a tariff has an optional add-on, this has been included as an additional observation. This issue affects 2013 and 2014 observations in particular. We do not consider this to be a significant issue as our overall results are not sensitive to dropping the years 2013 and 2014. We discuss this in footnote 87 in Annex 2.

with this data for a number of reasons. As discussed above, our dataset does not include observations for a number of SIM-only operators. We also note that we do not have observations for all contract lengths for all operators. This has the potential effect of introducing multicollinearity into the analysis, which may make our results unstable.

A1.8 We have also dropped SIM-only contracts of 6 months from our dataset. There were only five observations with this contract length in our dataset and these observations had unusually high prices. These five observations were also sold only by EE and would therefore have been correlated with the operator fixed effect.

A2. Estimation Results

- A2.1 In Section 4 we briefly discussed our main results. In this Annex we present the full set of regression results for all variables and controls.
- A2.2 Specifically, we present the following:
- a) Our main results for tariffs with handsets (with data allowances less than or equal to 20GB);
 - b) Our results for tariffs with handsets (all data allowances); and
 - c) Our results based on SIM-only tariffs.
- A2.3 For our main results for available tariffs with handsets (with data allowances less than or equal to 20GB), we consider both average price trends over time and by operator, which would be relevant for consumers choosing to move or adopt new tariff plans.

Our results for available post-pay tariffs with handsets with data allowances less than or equal to 20GB show the expected relationships

- A2.4 Table A2.1 below sets out the detailed results for our main regression. As discussed in Section 5 and Annex 3, we estimate our results using two functional forms. This allows us to obtain lower and upper bounds for our price trends.
- A2.5 Variables are grouped in this table according to the set of dummy variables or characteristics they represent (for example, handset quality). The results can be interpreted as follows:
- a) As data is included as a continuous variable, this estimate represents the expected impact on price of an additional GB of data.
 - b) To estimate our results, for each category of dummy variables (e.g. contract length) we have omitted one dummy variable (e.g. 24 month contracts). These omitted variables are represented in the table below by blank cells. We interpret the effect of the other dummy variables within that category (12 month, 18 month contracts) relative to the omitted variable. For example, we estimate that a 12 month tariff is between £20 and £24 more expensive per month on average than a 24 month tariff.⁶⁶
- A2.6 As the Box-Cox functional form does not produce easily interpretable results we have applied the chain rule in order to isolate the unique effect of each variable on price. A similar approach has been applied to the linear-log functional form in the case of the data variable.

⁶⁶ While the omitted dummy is a subjective choice, this choice does not affect the overall interpretation of results.

Table A2.1: Detailed estimation results for available tariffs with handsets⁶⁷⁶⁸

Variable	Coefficient estimate and standard error (£)	
	Box-Cox	Lin-Log
R-squared ⁶⁹	0.74	0.71
Basic handset		
Intermediate handset	5.98 (0.00)	4.68 (0.02)
Advanced handset	14.92 (0.01)	14.11 (0.02)
Contract length = 24 months		
Contract length = 12 months	19.65 (0.02)	23.59 (0.05)
Contract length = 18 months	12.52 (0.01)	12.15 (0.04)
Data (GB)	1.42 (0.00)	0.29 (0.00)
Limited minutes		
Unlimited minutes	3.57 (0.00)	4.54 (0.02)
Limited texts		
Unlimited texts	3.60 (0.02)	2.49 (0.03)
3G technology		
4G technology	-0.08 (0.01)	0.22 (0.02)
Carphone Warehouse		
Not Carphone Warehouse	2.54 (0.00)	2.62 (0.01)
Three		
EE	2.54 (0.01)	3.34 (0.03)
O2	2.18 (0.01)	2.94 (0.03)
Vodafone	1.91 (0.01)	2.66 (0.03)
MVNO	-0.04 (0.02)	1.21 (0.04)
2013		
2014	-4.73 (0.02)	-4.35 (0.02)

⁶⁷ We note that the general and specific regressions are the same in this case as all variables are significant at the 1% level.

⁶⁸ We have calculated the standard errors for the Box-Cox functional form using a technique called bootstrapping. This is a sampling with replacement technique in which the resulting empirical distribution is interpreted as an approximation to the true sampling distribution. We have re-sampled 100 times. We consider this to be sufficient as our confidence intervals are narrow. We have also calculated the standard error for the data variable of the linear-log functional form using bootstrapping. The other standard errors are those estimated using the command regress by Stata.

⁶⁹ The results for the R-squared and the adjusted R-squared (a version of the R-squared which takes account of the number of predictors in the model) are the same.

2015	-3.29 (0.01)	-2.47 (0.03)
2016	-5.02 (0.01)	-4.18 (0.03)
2017	-6.47 (0.01)	-5.54 (0.03)

Discussion of results of available post-pay tariffs with handsets with data allowances less than or equal to 20GB

- A2.7 **Handset quality.** Better quality handsets are associated with higher mobile tariff prices. A handset of advanced quality increases the tariff price by £14-£15 per month on average relative to a basic handset.
- A2.8 **Contract Length.** As discussed previously in paragraph 4.4 a), longer contracts are associated with cheaper mobile tariffs. This is consistent with operators using cheaper tariffs to incentivise consumers into signing up to longer contracts. Our results suggest that a contract length of 12 months increases the tariff price by between £20 and £24 per month relative to a tariff with a 24 month contract.
- A2.9 **Inclusive data.** As expected, high data packages are relatively more expensive than low data tariffs. We estimate that an additional 1GB of data increases monthly prices by between £0 and £1 on average. We note that this is the average impact across all the years in the dataset (2013-2017).⁷⁰
- A2.10 **Inclusive minutes.** We find similar results for inclusive minutes as for inclusive data. A tariff with unlimited minutes is approximately £4-£5 more expensive per month than a tariff with limited minutes.⁷¹
- A2.11 **Inclusive texts.** We also find similar results for inclusive texts as for inclusive data and minutes. A tariff with unlimited texts is approximately £2-£4 more expensive per month than a tariff with limited minutes.⁷²
- A2.12 **Technology.** We would expect consumers to be willing to pay a higher price for a 4G tariff, than for a tariff with 3G technology since 4G enables faster downloads and increases the quality of the user experience. A 4G tariff is not estimated to be much more expensive than a 3G tariff. This may be due to consumers not taking the technology into account when making their purchasing decisions. It may also be because the technology is correlated with another variable, for example, the year fixed effects. Looking at the simple correlation between these variables we note that the dummy variable for 4G is somewhat

⁷⁰ It is possible that the impact of additional data on tariff prices has changed over time if mobile consumers put a greater value on data consumption in recent years and mobile operators have been able to monetise this. For example, the average (including residential and business) monthly mobile data used per active connection increased by 225% between 2013 and 2016. Source: [Communications Market Report UK 2017](#), page 130. We have presented results which control for this in Annex 3.

⁷¹ Unlimited minutes have a weaker effect on expected tariff prices than unlimited data. We consider this to be unsurprising as consumers' purchasing decisions may be increasingly driven by data rather than minutes.

⁷² Unlimited texts have a weaker effect on the overall tariff price than unlimited data and minutes as consumers have become less reliant on their phone tariff for text messages with the increased usage of messaging applications which run over data networks (e.g. Whatsapp).

correlated with the year 2013 (the correlation coefficient is -0.64). This is unsurprising given that very few tariffs in our dataset were 4G in 2013 (3%).

A2.13 **Carphone Warehouse.** Tariffs retailed by Carphone Warehouse tend to be cheaper (by approximately £3 a month) than those sold by the operators themselves or other retailers. This is consistent with Carphone Warehouse being a discount retailer.

A2.14 **Operator controls.** We estimate Three to be relatively cheaper than the other MNOs, all else equal. For example, a tariff sold by an MNO other than Three is estimated to be approximately £2-£3 more expensive per month. MVNOs are estimated to be between £0 and £1 more expensive than Three. We control for the fact that operator effects may vary over time in our second specification discussed below.

A2.15 Time effect.

- a) The average price of mobile tariffs declined significantly between 2013 and 2014. This may be explained by a number of factors:
 - i) As discussed below, our results suggest that the average price decline between 2013 and 2014 was particularly steep for Three (£10 to £11). Our fixed effect for Three may not be picking up the entire effect of this price decline.
 - ii) The decline in prices may also be partly explained by the impact of the 4G rollout, which took place around this time. For most of 2013, Three was the only operator to offer 4G tariffs at no extra cost. At this time, EE included an explicit premium and Vodafone had a high minimum entry package. In contrast, in 2014, 4G pricing was “softer”.⁷³ For example, at the end of 2013, O2 began to offer 4G at no extra cost to 3G for tariffs above a certain speed. Our 4G variable may not be picking up the entire effect of this fall in 4G prices given the variance between operators in these earlier years.⁷⁴

⁷³ Enders Analysis, 2014. [UK mobile market Q4 2013](#), page 10.

⁷⁴As Three was already offering 4G tariffs at no extra cost in 2013, the decline in pricing between 2013 and 2014 may have been a reaction of the other MNOs to Three’s strategy of marketing itself as a relatively low cost provider.

- b) The increase in prices between 2014 and 2015 may be explained by a number of factors. This finding is consistent with our statement in the PSSR spectrum release consultation, where we found that the minimum prices for contracts including handsets increased by 12% between 2014 and 2015.⁷⁵ Based on that analysis, we suggested that the increase could be explained by an increase in the price of premium handsets or the additional cost of 4G packages. Although the difference in price between 3G and 4G tariffs declined between 2013 and 2014, some operators continued to charge a premium for 4G tariffs. The price increase between 2014 and 2015 may therefore also be partly explained by the removal of cheaper 3G tariffs in 2015.⁷⁶ For example, Vodafone removed its 3G option in 2015, forcing all pricing up to 4G levels.⁷⁷⁷⁸
- c) The average price of mobile tariffs continues to decline between 2015 and 2017. This suggests that consumers are paying less for their mobile tariffs, after controlling for other changes in quality characteristics.

A2.16 As discussed in Section 5, our results are based on the available tariffs in the market with data allowances less than or equal to 20GB. It is possible that tariffs with higher data allowances have experienced different pricing trends over the same period – see discussion in Section 4 and in paragraphs A2.23 onwards.

A2.17 Research from Enders Analysis suggests that consumers are increasingly buying higher data tariffs. Over a one-year period between mid-2016 and mid-2017, Enders Analysis found that the proportion of consumers paying for more than 5GB of data increased from a third of the market to 41%.⁷⁹ Although 41% of consumers are estimated to have data allowances greater than 5GB, we expect only a small proportion to have data allowances in excess of 20GB. This suggests that our analysis should capture the vast majority of consumers and so should reflect the pricing trends for consumers choosing to move or adopt new tariff plans.

Our detailed results suggest that price trends vary across the operators

A2.18 As discussed in Section 3, we have also specified a version of our main regression which allows us to estimate price trends by operator. As above, we estimate our results using two functional forms (Box-Cox and linear-log).

⁷⁵ Based on data in Figure A7.15, [Ofcom PSSR Consultation 2016](#).

⁷⁶ We note that under General Condition 9.6 mobile operators cannot initiate a contract change of “material detriment” without giving the customer the right to exit penalty free. Although we note that 3G tariffs are more likely to be low data tariffs, as shown in Table 6.1, analysis of our underlying dataset indicates that lower value tariffs do remain available. We are confident, therefore, that consumers who prefer to remain on cheaper tariffs with basic characteristics are not being made significantly worse off over time.

⁷⁷ Enders Analysis, 2015. [UK mobile market Q1 2015](#). Page 10.

⁷⁸ We note that some existing Vodafone 3G customers may have incurred a one-off £20 charge as a result of the transition from a 3G to 4G tariff. This applied only to those customers who chose to take up the new tariff.

⁷⁹ Enders Analysis, 2018. [Covert growth in UK mobile](#), page 28.

A2.19 Table A2.2 below sets out the detailed results for this regression. We interpret these results in a similar way to those in Table A2.1 above. As we are estimating year-specific operator effects, we now interpret our results for each operator and year combination relative to Three in 2013 (our omitted dummy variable). The results for the mobile operators (excluding Three) in 2013 represent the effect of a particular operator (relative to Three in 2013).

Table A2.2: Detailed estimation results for price trends by operator⁸⁰

Variable	Coefficient estimate and standard error (£) ⁸¹	
	Box-Cox	Linear-log
R-squared ⁸²	0.74	0.71
Basic handset		
Intermediate handset	5.91 (0.00)	4.60 (0.02)
Advanced handset	14.83 (0.00)	13.97 (0.02)
Contract length = 24 months		
Contract length = 12 months	19.83 (0.01)	23.80 (0.04)
Contract length = 18 months	12.03 (0.01)	11.42 (0.04)
Data (GB)	1.37 (0.00)	0.29 (0.00)
Limited minutes		
Unlimited minutes	3.98 (0.01)	4.93 (0.02)
Limited texts		
Unlimited texts	3.57 (0.01)	2.58 (0.03)
3G technology		
4G technology	-0.04 (0.01)	0.32 (0.02)
Carphone Warehouse		
Not Carphone Warehouse	2.34 (0.00)	2.40 (0.01)
Three (2013)		
Three (2014)	-10.20 (0.04)	-10.54 (0.12)
Three (2015)	-4.75 (0.03)	-5.08 (0.12)
Three (2016)	-5.50 (0.03)	-5.27 (0.10)

⁸⁰ We note that the general and specific regressions are the same as all variables are significant at the 1% level.

⁸¹ As above we have calculated the Box-Cox (and linear-log data coefficient) standard errors using a bootstrap approach (using 100 bootstrap samples).

⁸² The results for the R-squared and the adjusted R-squared (a version of the R-squared which takes account of the number of predictors in the model) are the same.

Three (2017)	-9.23 (0.02)	-9.05 (0.11)
EE (2013)	1.04 (0.03)	1.42 (0.09)
EE (2014)	-4.51 (0.04)	-4.40 (0.10)
EE (2015)	-2.63 (0.03)	-2.18 (0.10)
EE (2016)	-3.83 (0.04)	-2.93 (0.10)
EE (2017)	-7.00 (0.04)	-6.10 (0.10)
O2 (2013)	1.18 (0.03)	1.49 (0.10)
O2 (2014)	-3.71 (0.03)	-3.00 (0.10)
O2 (2015)	-3.42 (0.03)	-2.53 (0.10)
O2 (2016)	-5.94 (0.04)	-5.42 (0.10)
O2 (2017)	-6.81 (0.03)	-6.36 (0.10)
Vodafone (2013)	-1.08 (0.03)	-1.73 (0.10)
Vodafone (2014)	-3.83 (0.03)	-3.54 (0.10)
Vodafone (2015)	-2.91 (0.04)	-1.65 (0.10)
Vodafone (2016)	-4.88 (0.03)	-3.82 (0.10)
Vodafone (2017)	-6.75 (0.04)	-5.94 (0.10)
MVNO (2013)	-4.05 (0.05)	-4.08 (0.10)
MVNO (2014)	-7.62 (0.02)	-5.82(0.12)
MVNO (2015)	-5.20 (0.04)	-4.22 (0.10)
MVNO (2016)	-7.08 (0.03)	-6.07 (0.11)
MVNO (2017)	-5.00 (0.03)	-2.68 (0.12)

Discussion of results estimating price trends by operator

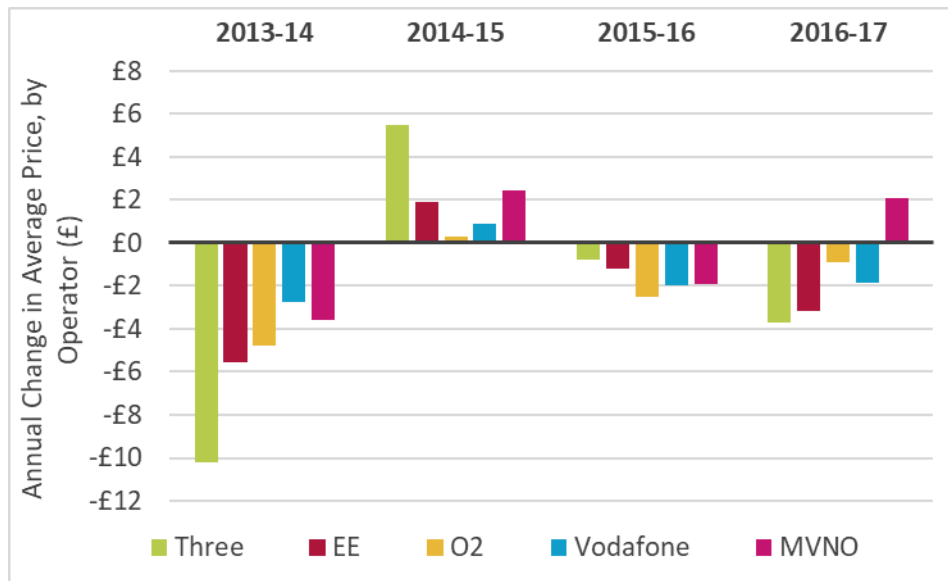
A2.20 The results for most of our explanatory variables are consistent with those for our main regression. We focus in this section on the the estimated price trends by operator and present these results in Figure A2.1 below. We present the results based on the Box-Cox functional form only for simplicity of presentation and as we consider it to be our main functional form. We note that the results are not significantly different based on the results of the linear-log functional form in Table A2.2 above.

A2.21 Our results suggest that, after controlling for changes in other quality characteristics:

- a) The average price of available mobile tariffs declined significantly between 2013 and 2014. Our results for this regression suggest that this effect was particularly strong for Three, which became £10 cheaper over this period.

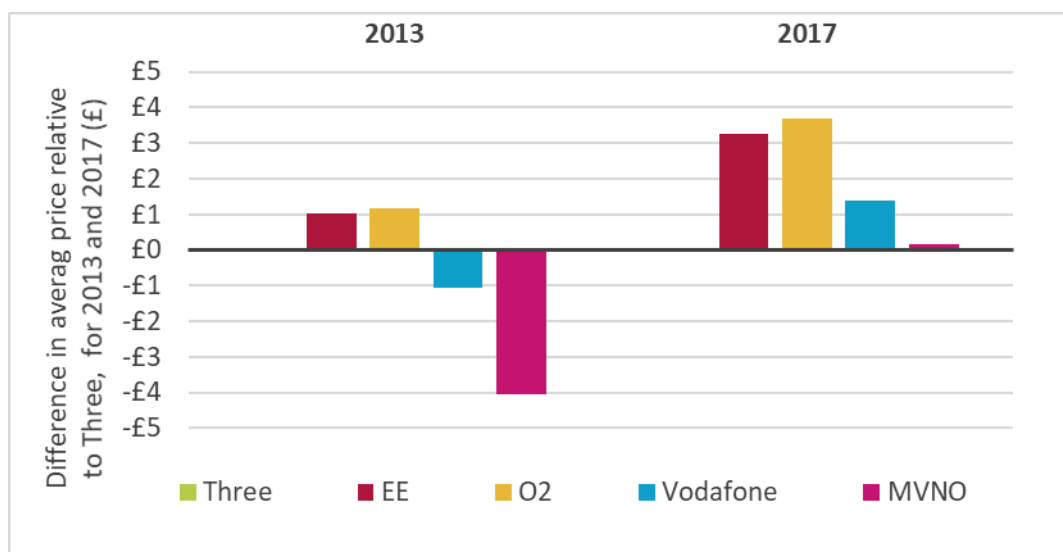
- b) The average price of available mobile tariffs increased between 2014-15, with a range of £0 (O2) to £5 (Three) across the operators.
- c) The average price of available mobile tariffs sold by the MNOs declined between 2015 and 2016 (£1 to £3) as well as between 2016 and 2017 (£1 to £4). The prices of mobile tariffs sold by the MVNOs declined by £2 on average between 2015 and 2016 but increased by £2 between 2016 and 2017.

Figure A2.1: Estimated change in the available (monthly) prices of post-pay plans, by operator (2013-2017)



- A2.22 Our results also suggest that, after controlling for changes in other quality characteristics:
- a) In 2013, EE and O2 were relatively more expensive than Three (£1) for tariff plans available in the market; whereas Vodafone and the MVNOs were relatively cheaper (£1 and £4 respectively).
 - b) By 2017, MVNOs were relatively cheaper than the MNOs (£1 to £4), with the exception of Three. Three is estimated to have been relatively cheaper than the other MNOs in 2017 (by £1 to £4) all else equal.

Figure A2.2: Difference in average price relative to Three (2013 and 2017)



Our results for all tariffs are not robust but show similar trends to tariffs with data allowances less than or equal to 20GB

A2.23 In this section we present our results based on all available tariffs including tariffs with data allowances greater than 20GB. This dataset contains 1.3 million observations. As discussed in Section 4, we do not consider these results to be robust. Specifically, tariffs with inclusive data allowances greater than 20GB appear to exhibit different price trends to tariffs with smaller data allowances. The inclusion of large data allowances, therefore, leads to results which are sensitive to different variations in the data points included in our analysis.

A2.24 Taking this into account, our indicative results, presented in Table A2.3 below, imply that the average prices of tariffs may have declined over time between 2013 and 2017 by £4.⁸³ Consistent with our results for tariffs with data allowances less than or equal to 20GB only, we see an initial increase in prices between 2014 and 2015, followed by a decline in average prices between 2015-16 and 2016-17.

A2.25 The flatter decline in prices between 2013 and 2017 (£4 vs £6 based on tariffs with data allowances less than 20GB) is driven by the inclusion of higher data tariffs in this dataset.

Table A2.3: Detailed estimation results for all post-pay tariffs with handsets available between 2013 and 2017⁸⁴

⁸³ Although not robust, we have also estimated results for tariffs with inclusive data allowances above 20GB. As can be inferred from the results in Tables A2.1 and A2.3, our results suggest that the average price of these high data tariffs increased between 2013 and 2017. This is driven by an even greater jump in prices between 2014 and 2015, with the average price of these tariffs declining between 2015 and 2017. This is broadly consistent with the results in Table 2.2, which illustrated that the average price of these high data tariffs increased between 2013 and 2017, before controlling for changes in quality and other characteristics.

⁸⁴ We note that the general and specific regressions are the same in this case as all variables are significant at the 1% level.

Variable	Coefficient estimate (£) ⁸⁵	
	Box-Cox	Linear-log
R-squared ⁸⁶	0.69	0.69
Basic handset		
Intermediate handset	6.40 (0.01)	4.61 (0.02)
Advanced handset	15.98 (0.01)	14.27 (0.02)
Contract length = 24 months		
Contract length = 12 months	19.22 (0.02)	23.64 (0.05)
Contract length = 18 months	13.97 (0.01)	13.27 (0.03)
Data (GB)	0.20 (0.00)	0.11(0.00)
Limited minutes		
Unlimited minutes	7.77 (0.02)	6.08 (0.02)
Limited texts		
Unlimited texts	2.68 (0.01)	2.14 (0.03)
3G technology		
4G technology	1.54 (0.01)	1.03 (0.02)
Carphone Warehouse		
Not Carphone Warehouse	2.98 (0.01)	2.96 (0.01)
Three		
EE	4.31 (0.01)	4.92 (0.03)
O2	2.98 (0.01)	4.70 (0.03)
Vodafone	3.90 (0.01)	4.83 (0.03)
MVNO	1.88 (0.02)	3.31 (0.04)
2013		
2014	-4.54 (0.00)	-3.89 (0.02)
2015	-2.06 (0.01)	-1.43 (0.03)
2016	-3.18 (0.01)	-2.55 (0.03)
2017	-3.97 (0.01)	-3.57 (0.03)

⁸⁵ As above we have calculated the Box-Cox (and linear-log data coefficient) standard errors using a bootstrap approach (using 100 bootstrap samples).

⁸⁶ The results for the R-squared and the adjusted R-squared (a version of the R-squared which takes account of the number of predictors in the model) are the same.

Our results for available SIM-only tariffs are not robust but are also broadly as expected

- A2.26 As we discuss in Section 6 (paragraphs 6.22-6.24), many studies considering pricing trends in mobile exclude handset data due to a concern that a preference for handsets rather than tariffs is being estimated. In our study, we have included handset data in our regression, and controlled for it using our handset quality variable, as we consider handsets to be an important factor in the mobile tariff offered to consumers.
- A2.27 Nonetheless, if there was a concern that the analysis was measuring preference for handsets rather than tariffs, one way of controlling for this is to estimate the regression based on SIM-only tariffs which do not have a handset attached.
- A2.28 As mentioned in Section 3, we also collected data on post-pay SIM-only plans. As we discuss in Annex 1, this dataset comprises of 1,456 observations, which are broadly distributed across the years 2013-2017. Although we present the results for SIM-only, we have a number of concerns with the SIM-only dataset, as discussed in Annex 1, and therefore do not consider these results to be robust. However, we note that, consistent with our results for tariffs with handsets (available in the market during this period), these results provide some support for the suggestion that the available prices of SIM-only plans have declined over time, all else equal.⁸⁷
- A2.29 In Table A2.4 we present comparable results based on the SIM-only data. We interpret these results in a similar way to our results for tariffs with handsets.
- A2.30 Our results are broadly as expected. We note that:
- a) The estimated pattern of prices across the MNOs is similar for SIM-only tariffs. Three is estimated to be approximately £1-3 cheaper per month than the other MNOs for tariffs with handsets, and between £0-3 cheaper for SIM-only tariffs.
 - b) As for tariffs with handsets, these results suggest that the prices of SIM-only tariffs have declined over time. However, whereas prices for tariffs with handsets increased between 2014 and 2015, prices of SIM-only tariffs appear to have declined steadily between 2013 and 2017.

⁸⁷ As discussed in Annex 1, due to the data collection process, a number of SIM-only tariffs have been double-counted. This issue affects 2013 and 2014 observations in particular. We do not consider this to be a significant issue as our overall results are not sensitive to dropping the years 2013 and 2014. Based on our full dataset we estimate a price decline of -£1.18 between 2016 and 2017 (based on the Box-Cox). After dropping 2013 and 2014 tariffs we estimate a price decline of -£1.52.

Table A2.4: Detailed estimation results for SIM-only tariffs

Variable	Coefficient estimate (£) ⁸⁸	
	Box-Cox	Linear-log
Adjusted R-Squared	0.56	0.48
Contract Length = 24 months		
Contract Length = 1 month	1.40 (0.32)	1.91 (0.99)
Contract Length = 12 months	0.57 (0.28)	1.20 (0.96)
Contract Length = 18 months	1.55 (0.28)	1.73 (1.09)
Data (GB)	0.58 (0.01)	0.25 (0.00)
Limited minutes		
Unlimited minutes	5.59 (0.16)	7.20 (0.47)
Limited texts		
Unlimited texts	1.07 (0.09)	0.88 (0.45)
3G technology		
4G technology	4.36 (0.11)	4.97 (0.46)
Three		
EE	2.51 (0.21)	1.57 (0.62)
O2	1.47 (0.23)	-0.05 (0.62)
Vodafone	3.12 (0.19)	2.56 (0.71)
MVNO	-1.69 (0.25)	-2.06 (0.65)
2013		
2014	-3.28 (0.12)	-3.53 (0.58)
2015	-4.18 (0.16)	-5.00 (0.61)
2016	-5.06 (0.14)	-5.76 (0.68)
2017	-6.24 (0.16)	-6.74 (0.72)

⁸⁸ As above we have calculated the Box-Cox (and linear-log data coefficient) standard errors using a bootstrap approach (using 100 bootstrap samples).

A3. Robustness Testing

A3.1 As discussed above, we have conducted a number of tests of the robustness of the analysis. This is important in assessing whether the results are driven by any specific factors or, instead, whether they are broadly robust. This Annex sets out in more detail the robustness tests we have undertaken. For conciseness we focus in this annex on the robustness of our first regression (Table A2.1). We note that our further results (Table A2.2) are also robust to the same tests.

A3.2 In particular, we discuss:

- a) our decision to present a range for our results based on the results of the Box-Cox test.
- b) the robustness tests we have undertaken to check how sensitive the results are to:
 - i) controlling for inclusive minutes and SMS allowances using continuous rather than dummy variables.
 - ii) controlling for inclusive data allowances using a dummy rather than a continuous variable.
 - iii) controlling for contract length using a continuous variable rather than dummy variables.
 - iv) controlling for MVNOs using controls for individual MVNOs rather than a group MVNO control and dropping MVNO tariffs from our dataset.
 - v) controlling for the impact on price of data allowances changing over time.
 - vi) controlling for other potential variables (throttling, tethering, SMS prices) to impact price.
 - vii) testing how sensitive our results are when alternative data thresholds (15GB and 25GB rather than 20GB) are used in the analysis.
 - viii) comparing our main results to the estimated weighted average price trends from our second specification.
 - ix) dropping tariffs retailed by Carphone Warehouse.

The Box-Cox test confirms that the relationship between price and quality is not linear

A3.3 As discussed in Section 3, a key consideration with hedonic analysis is that the relationship between price and the characteristics of the product may not be linear.

A3.4 To test for this, we estimated a Box-Cox model. The model allows us to estimate which non-linear transformation fits the data best and encompasses a linear model, a log-linear model and a wide range of models. The model includes two types of transformations:

Box-Cox transformation of price = $(price^\theta - 1)/\theta$

Box-Cox transformation of independent variables (i.e. the quality features of mobile tariff plans) = $(\text{independent variables}^\lambda - 1)/\lambda$

A3.5 The method reports the value of θ and λ that maximise the likelihood function.⁸⁹ Interpretation of the model parameters includes many common cases, such as:

Table A3.1: Box-Cox Results

θ and/or λ value	Transformation
1.00	Linear regression model
0.50	Square root transformation
0.33	Cube root transformation
0.00	Natural log transformation

A3.6 We can only run the Box-Cox test for our price and data allowance variables as all other variables in our specification are dummy variables (i.e. they only take on values of 0 or 1). On this basis, the Box-Cox test suggests a $\theta = 0.49$ for the dependent variable and a $\lambda = 0.24$ for the data variable. There are a number of ways in which we could use this to inform our choice of model specification. Three obvious ones are:

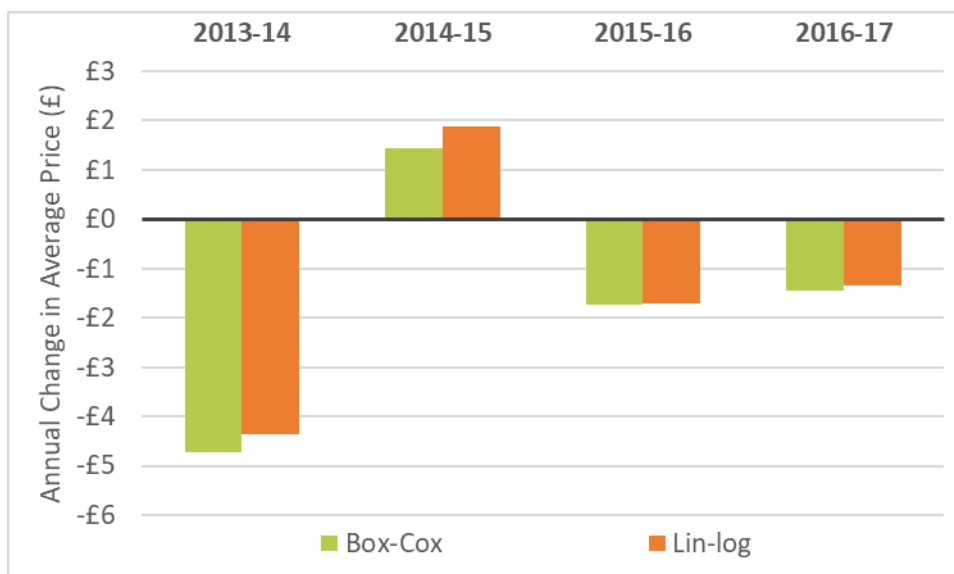
- i) Strictly use the results from the Box-Cox model.
- ii) Use values which are close to the Box-Cox model but are easier to conceptualise and interpret. Here we assume a $\theta = 1$ (which is equivalent to a linear transformation) and $\lambda = 0$ (a log transformation). These values are chosen because they are the closest meaningful values to those indicated by the Box-Cox model.
- iii) Ignore the test results and assume a linear relationship instead.

A3.7 In Figure A3.1 below, we set out the results from running the analysis using transformations (i) and (ii). Although the strict Box-Cox transformation produces the functional form which fits the data best⁹⁰, we also present our results using transformation ii) to reduce the risk that we are overestimating the true price decline. We do not consider it appropriate to use a linear relationship based on the results of the Box-Cox test. Figure A3.1 suggests that using these two different functional forms does not significantly affect our main result that prices are falling over time.

⁸⁹ The likelihood function calculates the probability of observing a given dataset for each value of θ and λ .

⁹⁰ We note that the version of the Box-Cox applied by Stata may not be heteroskedasticity-robust. However, our results are not sensitive to variations of lambda and theta which suggests that our results are robust to heteroskedasticity.

Figure A3.1: Results using a range of functional forms



A3.8 Comparing these models cannot simply be done using standard tools such as the adjusted R-squared⁹¹ or RMSE⁹². A limitation of the R-squared as a measure of goodness of fit is that a high R-squared may be caused by either overfitting of variables (too many variables for the number of observations), or an improved regression specification. RMSE cannot be used in this case as the dependent variable has been transformed differently.

A3.9 Other measures of fit include the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) tests of model selection. However, like the RMSE, these cannot be used to compare models which have different dependent variables.

We have carried out a number of robustness tests of our results for post-pay tariffs

A3.10 As outlined at paragraph A3.2 above, we have carried out a number of robustness tests to check how sensitive our results are to change.

A3.11 In this section, we graph our results using only the Box-Cox functional form for simplicity of presentation and as we consider these to be our main results.

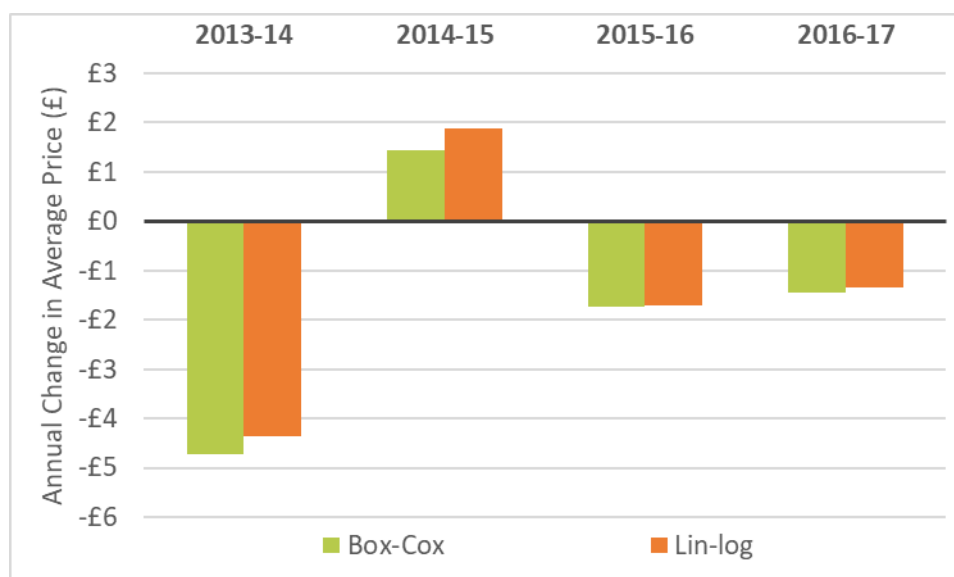
⁹¹ R-squared evaluates the scatter of the data around the fitted data line and takes a value between 0 and 1 [perfect fit].

⁹² The mean squared error (MSE) measures the average of the squares of the errors—that is, the difference between the estimated coefficient and the data being estimated. The model with the better fit is the one with the lower (root) MSE.

Controlling for inclusive minutes and SMS allowances using continuous rather than dummy variables

- A3.12 Our data – see discussion in Section 4 and Annex 1 - includes unlimited minutes and SMS allowances which we cannot directly include in the analysis since they have no numerical value.
- A3.13 As discussed in Section 4 and Annex 1, in our main specification we use dummy variables for minutes and texts allowances as a way of including unlimited allowances in the analysis. We have created a dummy variable for each of minutes and SMS allowances which equals one if an observation has unlimited minutes/texts and zero otherwise.⁹³
- A3.14 Here, we test an alternative option which is to include minutes and texts allowances as continuous variables. We assign a range of values to unlimited allowances including:⁹⁴
- 15,000 minutes and 8,000 texts
 - 20,000 minutes and 10,000 texts
- A3.15 Our analysis in Figure A3.2 suggests that our approach is robust to this alternative option since using continuous variables for texts and minutes rather than dummy variables does not significantly impact our results.

Figure A3.2: Comparing results specifying minutes and text allowances as continuous and dummy variables



⁹³ 46% of observations in our dataset have unlimited minutes and 78% of observations have unlimited texts.

⁹⁴ The maximum minutes allowance in our dataset is 10,000 minutes and the maximum texts allowance is 5,000 texts. We therefore consider (a) and (b) to be reasonable values to assign to unlimited allowances as they represent 1.5 times and double the next largest allowance value.

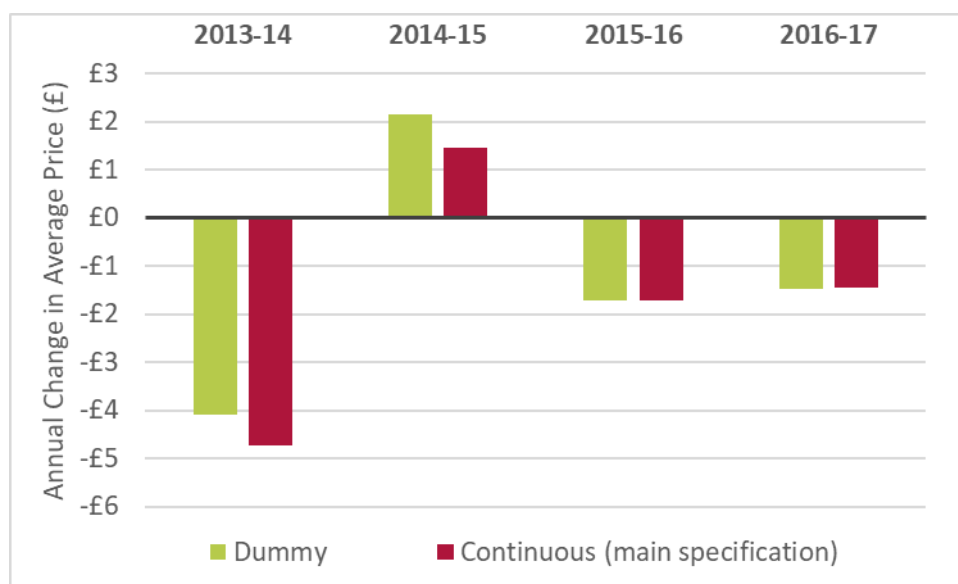
Controlling for inclusive data allowances using a dummy rather than a continuous variable

A3.16 As discussed in Section 4, we have chosen a different specification for data allowances than for minutes and texts allowances. We chose to include data as a continuous variable, rather than as a dummy variable for the following reasons:

- a) We have excluded unlimited data allowances from our analysis, so we are not required to make a subjective assessment of the value to assign to unlimited allowances.
- b) As we expect data to be a stronger driver of tariff prices than minutes or texts, the choice of categories for data allowances is likely to have a greater impact on our results than for minutes or texts.
- c) In order to avoid a risk of multicollinearity between the data categories and the other control variables, we would have had to specify very wide data categories (0-6GB, 7GB-Unlimited).⁹⁵ This would have reduced the usefulness of the information gained from splitting the data variable into more granular categories.

A3.17 Here, we test the robustness of our approach to specifying data allowances as dummy variables instead. As shown in Figure A3.3 below, including data as a dummy variable has a limited impact on our overall results compared to the results using a continuous variable.

Figure A3.3: Comparing results specifying data as a continuous and dummy variable



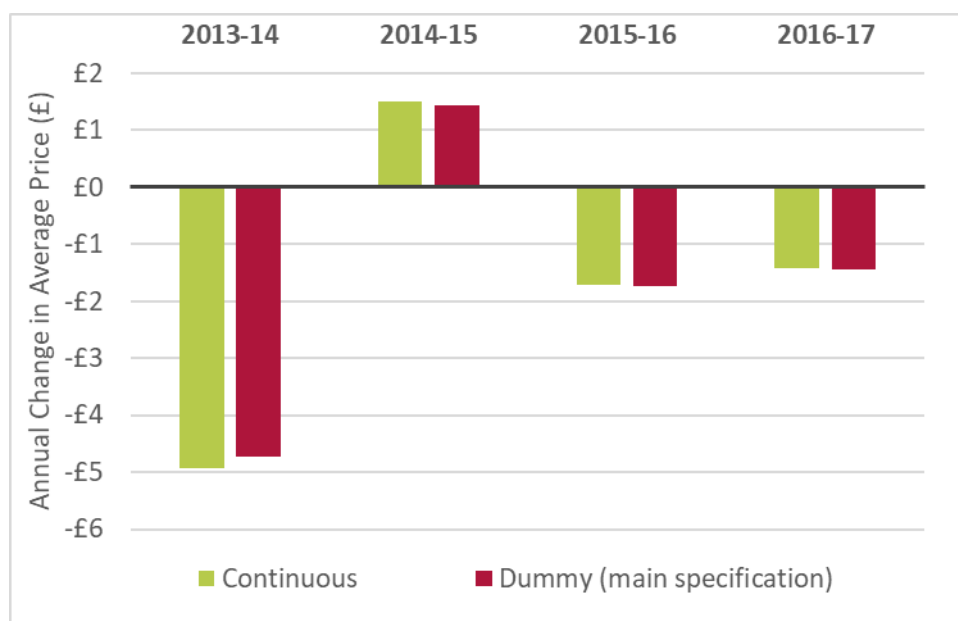
⁹⁵ We have chosen the categorisation 0-6GB, 7GB-Unlimited as this categorisation best reduces the risk of multicollinearity as discussed in paragraph A3.16.

Controlling for contract length using a continuous variable rather than dummy variables

A3.18 In our main specification we have included contract length as a group of dummy variables (whereby a dummy variable is created for each contract length). This is based on the fact that contract lengths are restricted to a limited number of values. An alternative option is to include contract length as a continuous variable.

A3.19 As shown in Figure A3.4, including contract length as a continuous variable does not significantly affect our overall results.

Figure A3.4: Comparing results specifying contract length as continuous or dummy variables



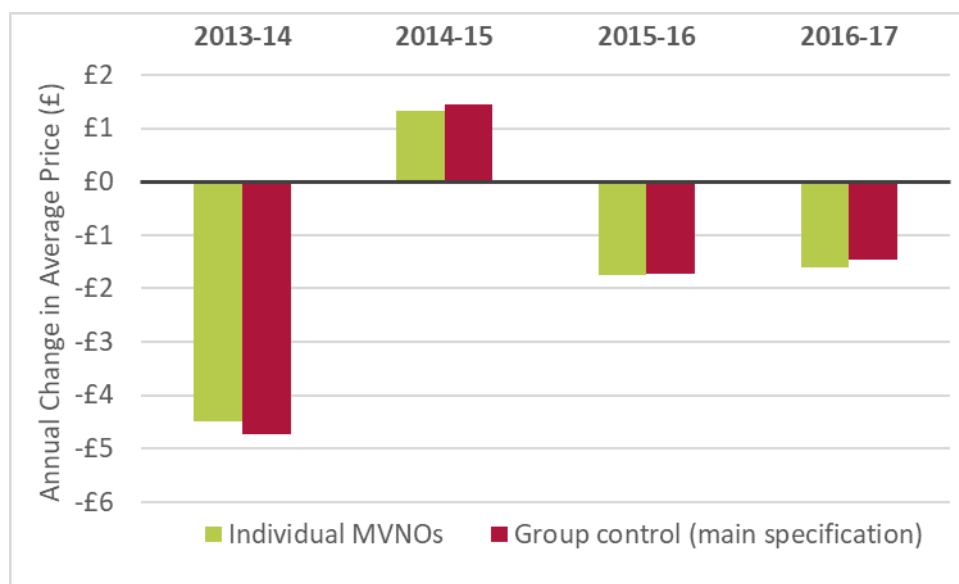
Controlling for MVNOs using individual controls rather than a group control and dropping MVNO tariffs from our dataset

A3.20 Our main specification includes a single dummy variable for all MVNOs which takes a value of one if the operator is an MVNO and zero otherwise. An alternative approach is to include operator-specific dummy variables.

A3.21 However, we consider our main specification to be more appropriate for the following reasons:

- a) We have some concerns regarding the completeness of our MVNO dataset. For example, we are concerned that we only have data for a limited number of MVNOs.⁹⁶ As discussed at paragraph A3.22 below, our results are robust to dropping MVNO tariffs from our dataset. We therefore include these tariffs in our analysis but do not attempt to estimate individual MVNO effects.
- b) As shown in Figure A3.5, this choice of specification has almost no impact on our main result that prices are falling over time.

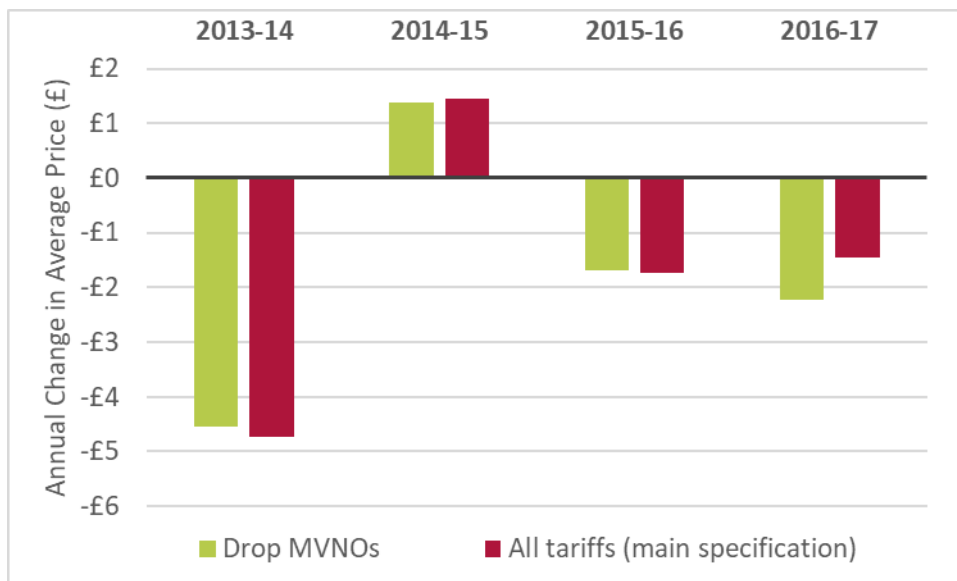
Figure A3.5: Comparing results using individual or joint MVNO controls



A3.22 As illustrated in Figure A3.6 below, we have also tested dropping the MVNO tariffs (10% of the dataset) from our dataset. This has the impact of making the price decline between 2016-17 steeper, all else equal. However, we consider it appropriate to include these tariffs in our main specification as we are interested in trends for all mobile tariffs.

⁹⁶ The MVNOs included in our dataset are: TescoMobile, VirginMobile and TalkMobile. LifeMobile is also captured within our operator control for EE. We have concerns that we do not have data for all tariffs sold by the operators in the dataset and are missing data for some MVNOs.

Figure A3.6: Comparing results dropping MVNO tariffs



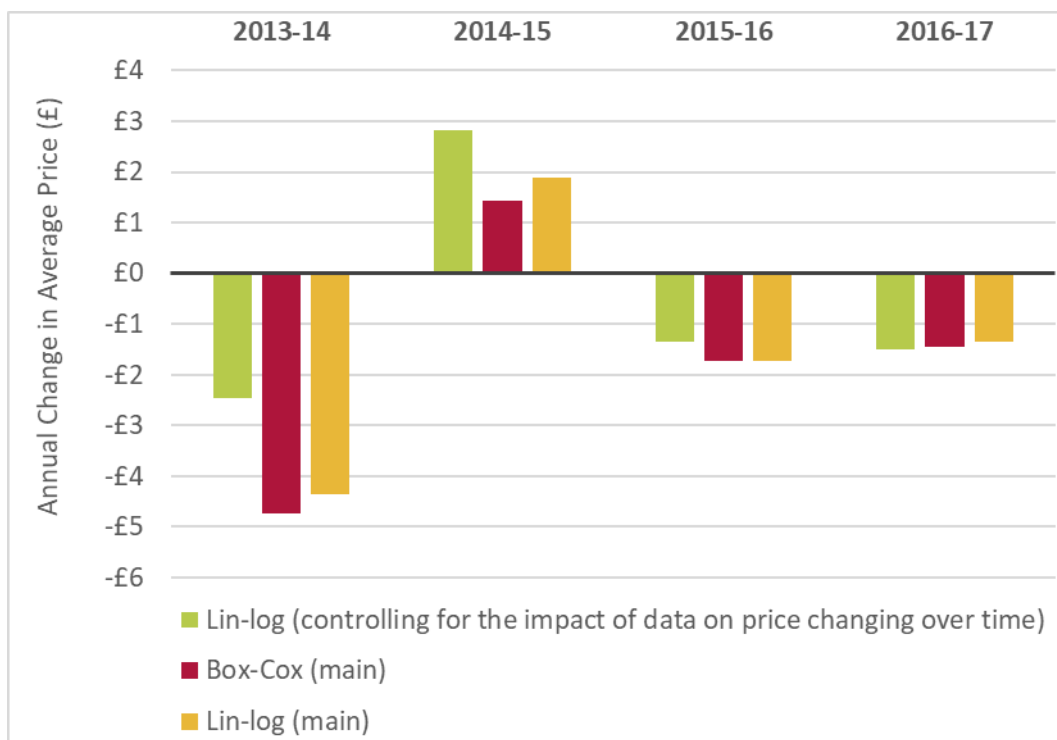
Controlling for the impact of data on price changing over time

A3.23 As discussed in Section 6, the impact of data on price may vary over time. We have tested for this by adding interaction terms which interact the continuous data variable with the year dummy variables. As shown in Figure A3.7 below, based on the linear-log functional form, our main results are broadly similar for both specifications.

A3.24 We note that the results for the 2013-14 and 2014-15 estimated price changes are somewhat different. However, as we cannot estimate the Box-Cox model for this specification we cannot tell whether the functional form we have used is appropriate⁹⁷. As our results are significantly affected by the functional form used, we cannot rely on the estimated price changes for this specification.

⁹⁷ This is because the Box-Cox test of functional form cannot simultaneously estimate the optimal transforms for single-variable predictors and for interaction terms that depend on them.

Figure A3.7: Controlling for the impact of data on price changing over time



Controlling for other potential variables

A3.25 We have also run the following sensitivities which we do not present in this annex. These sensitivities have limited impact on the overall pattern of prices:

- a) **Control for throttling.** Throttling refers to the intentional slowing of the internet service by the provider when a consumer consumes above a certain amount of data. In theory, this could be a determinant of mobile tariffs if consumers have a lower willingness to pay for a service which is throttled. However, we have excluded throttling from our main regression on the basis that we do not expect residential mobile consumers to pay attention to whether a contract allows throttling when making their purchasing decisions.
- b) **Control for tethering.** Tethering is the practice of using one device to connect another to the internet. As discussed in paragraph 6.28, consumer survey evidence suggests that only a small proportion of consumers take “added extras” into consideration when choosing tariffs. We also understand that most operators currently offer tethering as part of their mobile tariff. We note that, to the extent that consumers do pay attention to these features, and if some operators have not offered tethering in the past, this may affect the time and operator dummies as these features are not offered in all time periods by all operators.

- c) **Control for SMS prices.** We have excluded SMS prices from our main regression on the basis that we do not expect out of contract prices to have significant pricing implications. As we discuss in Section 6, we consider that consumers generally purchase contracts whose inclusive allowances broadly represent their preferences.

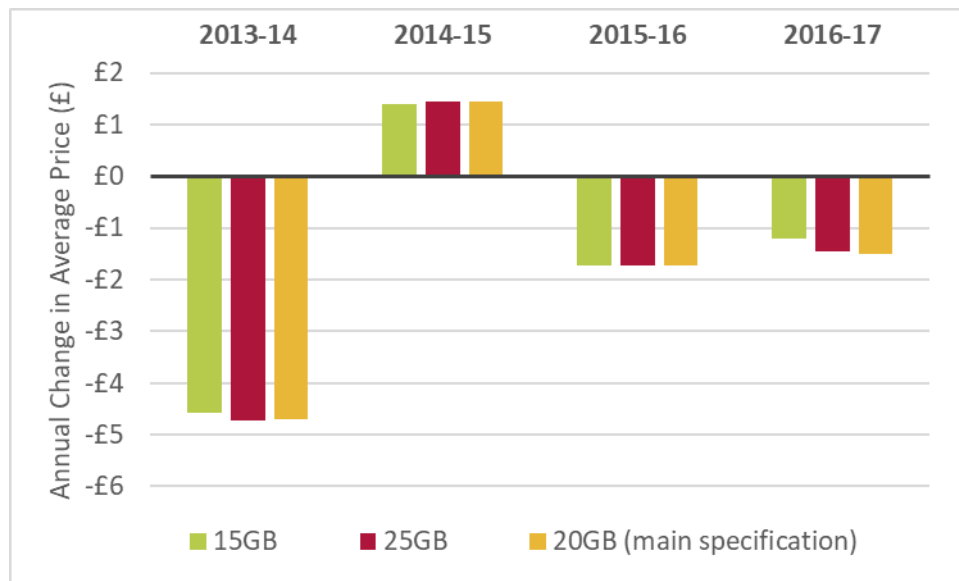
Testing alternative data thresholds (15GB and 25GB rather than 20GB)

A3.26 As discussed in Section 4, we have excluded from our analysis tariffs with data allowances greater than 20GB. This was based on analysis which indicated that those tariffs exhibited a different relationship between data allowances and prices than tariffs with data allowances less than or equal to 20GB. We have tested whether our results are sensitive to setting the threshold for inclusion in the regression higher or lower than 20GB by testing the effect of setting the threshold at the following levels:⁹⁸

- a) 15GB
- b) 25GB

A3.27 As shown in Figure A3.8, changing the threshold for our regression has limited impact on our main results.

Figure A3.8: Comparing results setting different data thresholds



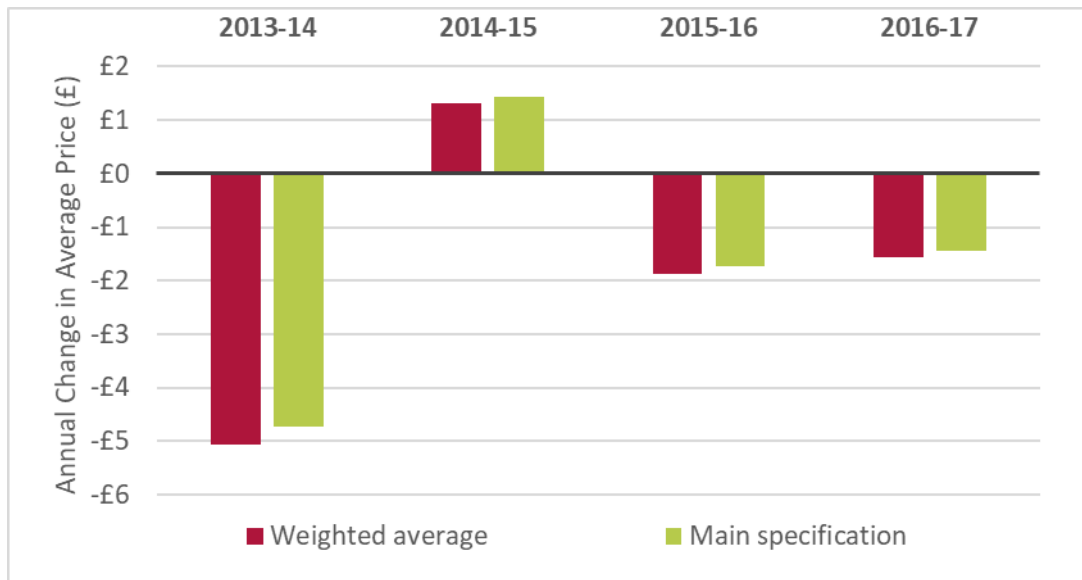
Comparing our main results to the estimated weighted average price trends from our second specification

A3.28 Our main results (presented in Table A2.1) do not control for differences in price trends across operators. However, we have chosen to present this regression as our main specification as we are mainly interested in pricing trends over time. Our further results (presented in Table A2.2) do not estimate the unique effect of time on price.

⁹⁸ This represents a range of plus and minus 5GB around the 20GB threshold included in our main specification.

A3.29 In order to compare the estimated pricing trends across these specifications we have calculated weighted average effects (weighted by the proportion of tariffs associated with the particular operator in that year) from the results in Table A2.2. As shown in Figure A3.9 below, these weighted average results are consistent with those of our main results.

Figure A3.9: Comparing estimated price trends across specifications



Dropping tariffs retailed by Carphone Warehouse

A3.30 We have also tested whether our results are stable when tariffs retailed by Carphone Warehouse are dropped from the dataset. We find that dropping these observations does not significantly affect our main findings.