Appendix 2: Technical analysis of methodology and results of econometric estimation of the impact of DTT availability on subscriptions to Sky's pay TV services

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January 13, 2009

1 Introduction: the idea of this study

1. The purpose of this technical appendix is to report the approach and results of an econometric study on the effect of the digital free-to-air TV services marketed under the Freeview banner on subscriptions to Sky's pay TV services in the United Kingdom in greater detail than the main body of the report. Such a study is one of the only ways to obtain reliable evidence about the extent to which free-to-air broadcasting exerts a competitive discipline on pay TV. We exploit the fact that Freeview's coverage of the United Kingdom remains significantly incomplete for technical reasons; variations in this coverage therefore provide a measure of variation in the alternatives available to potential subscribers to Sky's pay TV services.

2. The idea of using Freeview availability for this purpose is not new to this study, but was first undertaken in the unpublished paper "Regression analysis of effect of DTT on Sky subscriptions" submitted by Sky to

the Competition Commission in the context of the investigation of the acquisition by Sky of a stake in ITV. The latter paper asks a similar question to ours, although we go beyond the previous work in a number of ways that we describe below. In doing so we are fortunate to have obtained from Sky a dataset consisting of an updated version of the data used for the modelling in Sky's study, as well as a number of additional variables supplied at our request. As a result we are able to corroborate the strong negative relationship between Freeview availability and Sky subscriptions estimated in Sky's study and to verify the extent of its robustness to a number of statistical concerns.

3. Our procedure is similar in some respects to that used in medical research to estimate the effect of medical treatments on health outcomes. A medical study might consider, for instance, what effect a treatment such as the fluoridation of drinking water has on the frequency of dental cavities, by comparing localities whose water has been treated with areas whose water has not (if indeed such variation is observed). In a similar spirit we estimate the impact of a treatment which consists in making Freeview available in a locality on the willingness of households in that locality to subscribe or continue to subscribe to Sky's pay TV services. Our measure of treatment is only partial, however. We do not observe whether or not individual households can receive Freeview; instead our data are aggregate data at the postcode district level. Freeview availability is not typically uniform within postcode districts. We can, however, measure the proportion of households with access to Freeview within a postcode district and see to what extent variations in this proportion are associated with variations in subscriptions to Sky's pay TV services.

4. What we find is very clear. Controlling for a range of other variables, we observe that postcode districts that have higher access to Freeview also have, on average, significantly lower levels of subscriptions to Sky's pay TV services, and to a degree that implies Freeview is an important competitive constraint upon Sky. We go on to investigate the extent

to which this statistical association can be used to infer causation. We perform a number of checks of robustness of our results, which confirm the importance of the competitive constraint exercised by Freeview upon Sky.

5. Two main difficulties arise in inferring causation from the statistical association we have documented. The first difficulty concerns the extent to which we can be sure that we have really controlled for all other variables that might be responsible for the apparent association of Freeview availability and subscriptions to Sky's pay TV services. One factor for which we control is the availability of cable television, which tends to be higher in areas that also have higher availability of Freeview. Including cable availability as an explanatory variable somewhat reduces the significance of Freeview, although high Freeview availability remains strongly associated with lower Sky subscriptions, to a degree that is both statistically significant and economically important. We also include a number of control variables. We control for characteristics such as income and demographics, and also for the characteristics of localities such as density of population. These controls are highly significant but including them strengthens rather than weakens the original negative correlation between Freeview availability and subscriptions to Sky's pay TV services. We cannot of course be absolutely certain that we have included all relevant control variables (no scientific study can ever be absolutely certain) but we believe we have made a reasonable attempt to do so.

6. The second difficulty concerns whether the availability of Freeview is a genuinely random policy, akin to a truly randomized medical trial. After all, when DTT transmitters were first installed this was not for the purpose of helping future economists to investigate their effect on demand for pay TV. We need to consider whether there might be unobserved factors that could have determined the geographical pattern of Freeview availability in ways that were correlated in turn with the tastes of viewers for Sky programmes. If that were so, then Freeview

availability could no longer be considered a truly random treatment and any estimation of its impact on demand for subscriptions to Sky's pay TV services based on such an assumption would be flawed - Freeview would be endogenous and the parameter estimates based on estimation by the usual technique of Ordinary Least Squares (OLS) would be biased.

7. A useful analogy is with medical studies of the effect of breastfeeding on the IQ of children. Many studies have been performed, going back as early as 1929, and most have found higher IQ among children who were breastfed. Later studies, however, have pointed out that it was unlikely that the decision whether or not to breastfeed children was taken purely at random. On the contrary, mothers with higher IQ were more likely than those with lower IQ to breastfeed their children, and it was principally the mothers' IQ that seemed to be responsible through inheritance for the higher IQ of the breastfed children (see Der et.al. (2006) for a recent study controlling for maternal factors including IQ, as well as for a survey of this literature). This shows that the original studies were flawed in concluding causality from correlation, but left open the question of whether the influence of mothers with higher IQ worked solely through the heritability of IQ and through other factors in the maternal environment, or whether there was also an effect through breastfeeding.

8. In order to make a proper investigation of a treatment it is necessary to find a truly random way of assigning the treatment across subjects (whether these are individuals or localities). In medicine this is typically done by the use of double-blind randomized clinical trials, but that is hardly possible for a treatment such as the one we are considering here. A closer analogy would be a study that analyzed the effect of diet on the risk of developing certain kinds of cancer. Suppose a study wanted to investigate the hypothesis that eating wholemeal bread over several years reduces the risk of bowel cancer. Data are available on the bread consumption of a panel of subjects, but the study could not

simply look for a correlation between wholemeal bread consumption and bowel cancer, since the decision to consume wholemeal bread is far from random. It may be influenced by all kinds of factors, such as income and education (and even awareness of the risks of bowel cancer, an awareness that may be higher among the educated). So instead one way to look for evidence might be to examine the effect of a truly random factor that determines whether or not people eat wholemeal bread, such as the presence of an allergy to gluten (on the assumption that this is determined by some genetic factor that is otherwise unrelated to cancer risk). If it could be established that people whose gluten allergy led them to eat less bread faced higher bowel cancer risk, this would count as a genuinely random natural experiment. In the terminology of statistics, gluten allergy is an "instrumental variable" for bread consumption - it predicts bread consumption but apart from its effect via bread consumption it is truly random with respect to cancer risk.

9. In this spirit, we have sought in this study to find suitable instrumental variables for the availability of Freeview. As we discuss in section 4 we use the distance of localities from the DTT transmitters as such an instrument. The digital transmitters have been constructed on the largest of the old analogue masts that were erected across the UK several decades ago, and there seems no reason to believe that the geographical distribution of these large masts is anything but random with respect to the underlying preferences of viewers for pay TV. In this way we are able to obtain an estimate of the true underlying impact of Freeview availability on subscriptions to Sky's pay TV services which is robust to concerns about endogeneity.

10. As well as asking whether the treatment effect is statistically significant (that is, larger than is likely to be explained by chance) we also ask whether it is economically significant - that is, large enough to make an important difference to the competitive constraints on Sky. We approach this question in two ways. First, we give a sense of the importance of the treatment effect of Freeview availability by comparing

it with changes in the availability of cable in the same locality. This allows us to measure whether Freeview is as close a substitute for Sky subscriptions as cable subscriptions are. Since cable television has been traditionally regarded by competition law and policy (in the UK) as being an important enough competitive constraint to count as being in the same relevant market as pay TV services delivered by satellite, this provides a threshold for considering the effect of Freeview availability as economically important.

11. Secondly, we provide a calibration of the impact of Freeview availability in terms of consumers' willingness to pay. How much less is the average consumer willing to pay for Sky's pay TV services when the availability of Freeview in a locality increases, and is this a significant proportion of the monthly subscription fee?

12. The structure of this technical appendix is as follows. In section 2 we set out a formal mathematical model of households' viewing decisions that motivates and justifies the specification of our econometric estimation. This section is somewhat mathematical but can be omitted by readers uninterested in the technical details without jeopardizing the intelligibility of the remaining sections. Section 3 describes our data. Section 4 provides the results of the estimation and describes a number of tests of robustness. Section 5 explores the economic significance of the size of the impact of Freeview availability on subscriptions to Sky's pay TV services, as estimated by the study.

2 The choice model and its estimation

13. In this section we develop a formal model of households' viewing decisions and derive a testable econometric specification. Households h in a local area $a = a(h)$ can have access to DTT ($D_h = 1$) or not ($D_h = 0$). In what follows we use the phrase "availability of DTT" to indicate that households have the technological possibility of adopting Freeview if they wish (for instance by buying a suitable set-top box);

whether they do in fact adopt Freeview will be a decision for them to take.

14. Suppose that the value for household h of the available options for watching TV is:

    - $V_h(Sky)$ if the household subscribes to Sky
    - $V_h(Freeview)$ if the household adopts Freeview and does not subscribe to Sky (this needs also to be defined in the counterfactual state when DTT is not available, namely when $D_h = 0$).
    - $V_h(NBA)$ if the household neither subscribes to Sky nor adopts Freeview, but chooses the best alternative (besides Sky or Freeview).

    The following two latent variables (that is, variables that are not directly observed but which capture underlying preferences) determine the subscription to Sky's pay TV services in both states of the world:

    - $Y^*_{0h} = V_h(Sky) - V_h(NBA)$ when the household lives in a home where DTT is not available ($D_h = 0$). If the value of the subscription to Sky's pay TV services is larger than the value of the next best alternative (i.e. $Y^*_{0h} > 0$) then the household subscribes to Sky.
    - $Y^*_{1h} = V_h(Sky) - \max(V_h(Freeview), V_h(NBA))$, when the household lives in a home where DTT is available ($D_h = 1$). If the value of the subscription to Sky's pay TV services is larger than the value of the next best alternative, NBA, or DTT (i.e. $Y^*_{1h} > 0$) then the household subscribes to Sky.

15. We get:

$$Y^*_{1h} = Y^*_{0h} - \max(V_h(Freeview) - V_h(NBA), 0) \leq Y^*_{0h}.$$

    This means that the latent variable that predicts Sky subscriptions will take a value in the presence of Freeview that is equal to or lower than its value in the absence of Freeview. Those households for which its value is strictly lower are the ones for whom access to Freeview may make a difference to their choice of which television services to use.

2.1 Aggregation

16. As we have aggregate data and as the model is non linear, the explanatory variables determining the different values are also written at the aggregate level. Let u_{0h} be the difference between the latent variable for a particular household and its mean value for the postcode district. It is defined by the relation:

$$Y_{0h}^* = E(Y_{0h}^* \mid h \in a) + u_{0h}$$

where u_{0h} is mean independent of $a(h)$ by construction. We thus have within district a:

$$\begin{cases} Y_{0h}^* = \alpha_a + u_{0h} \\ Y_{1h}^* = \beta_a + u_{1h} \end{cases}$$

where, for instance, $\alpha_a = E(Y_{0h}^* \mid h \in a)$ is the average value difference between Sky and the next best alternative in a world where DTT does not exist.

17. The data on Sky subscriptions provide an estimate of $\Pr(Y_h = 1 \mid h \in a)$ where:

$$Y_h = 1 \text{ if } Y_{0h}^* > 0, D_h = 0 \text{ or if } Y_{1h}^* > 0, D_h = 1$$

is the actual subscription to Sky's pay TV services. Although the data on Sky subscriptions may contain some measurement error, we assume that the magnitude of these measurement errors is small and that they contribute little to the randomness of the data, since Sky has direct access to its own subscriber information. We thus treat Sky subscriptions and all variables at the postcode level as if they were exact values.

18. We derive:

$$\Pr(Y_h = 1 \mid h \in a) = \Pr(Y^*_{0h} > 0, D_h = 0 \mid h \in a) + \Pr(Y^*_{1h} > 0, D_h = 1 \mid h \in a)$$

which can be expanded as:

$$\begin{aligned}
\Pr(Y_h &= 1 \mid h \in a) = \Pr(Y^*_{0h} > 0 \mid D_h = 0, h \in a) \Pr(D_h = 0 \mid h \in a) \\
+ \Pr(Y^*_{1h} &> 0 \mid D_h = 1, h \in a) \Pr(D_h = 1 \mid h \in a) \\
&= S_a(-\alpha_a).(1 - \pi_a) + T_a(-\beta_a)\pi_a \\
&= S_a(-\alpha_a) + (T_a(-\beta_a) - S_a(-\alpha_a))\pi_a,
\end{aligned}$$

where $S_a(-\alpha_a) = \Pr(Y^*_{0h} > 0 \mid D_h = 0, h \in a)$ is the probability of subscribing to Sky conditional on not receiving DTT, $T_a(-\beta_a) = \Pr(Y^*_{1h} > 0 \mid D_h = 1, h \in a)$ is the probability of subscribing to Sky conditional on receiving DTT, and π_a is the probability of receiving DTT:

$$\pi_a = \Pr(D_h = 1 \mid h \in a).$$

19. It is important to note that the quantities $S_a(-\alpha_a)$ and $T_a(-\beta_a)$ can be interpreted as stable (or structural) parameters which do not vary with the installation of additional DTT transmitters or other changes in the environment (Heckman and Vytlacil (2007)), only if:

$$\Pr(Y^*_{jh} > 0 \mid D_h = j, h \in a) = \Pr(Y^*_{jh} > 0 \mid h \in a), \text{ for } j = 0, 1.$$

or, equivalently, that unconditional household tastes for TV subscriptions are independent of DTT availability. This is a condition that cannot be tested but must be imposed in order to interpret the data. Because the data are aggregate subscriptions at the post-code level, we express this idea in the form of the assumption:

$$(Y^*_{0h}, Y^*_{1h}) \perp D_h \mid h \in a. \quad (1)$$

which says that within each postcode, household valuations of television viewing possibilities are independent of access to DTT. As a consequence, because $Y^*_{1h} \leq Y^*_{0h}$ for all h:

$$T_a(-\beta_a) - S_a(-\alpha_a) \leq 0.$$

2.2 Treatment parameters

20. In a situation where π_a is set by a random policy intervention (independently of the characteristics of a) the *marginal treatment effect* (MTE) would be:

$$\frac{\partial}{\partial \pi_a} \Pr(Y_h = 1 \mid h \in a) = T_a(-\beta_a) - S_a(-\alpha_a) \leq 0.$$

Yet π_a is not set by such a random intervention, and the distribution of π_a is likely to be systematically related to a. For simplicity, we write linear functions:

$$S_a(-\alpha_a) = Z_a\gamma_0 + \varepsilon_{0a}, T_a(-\beta_a) = Z_a\gamma_1 + \varepsilon_{1a},$$

where γ_0 and γ_1 measure respectively the impact of the district's characteristics (such as demographics and geographics) on the demand for Sky's pay TV services with and without DTT availability. We then get the demand for Sky's pay TV services (in terms of probabilities):

$$q_a = \Pr(Y_h = 1 \mid h \in a) = Z_a\gamma_0 + Z_a(\gamma_1 - \gamma_0)\pi_a + \varepsilon_{0a} + (\varepsilon_{1a} - \varepsilon_{0a})\pi_a. \quad (2)$$

Any correlation between π_a and $\varepsilon_{0a} + (\varepsilon_{1a} - \varepsilon_{0a})\pi_a$ would make the OLS estimate inconsistent.

2.3 Estimation

21. For simplicity, we assume that the treatment is not heterogeneous across postcodes. In other words, there are no systematic differences between the effect of receiving DTT in one postcode and in another. It

implies that $\varepsilon_{1a} - \varepsilon_{0a} = 0$ and that $Z_a(\gamma_1 - \gamma_0) = \delta_1$ (say) in equation (2). This homogeneity assumption also has the specific consequence that the effect of increasing DTT availability by 10% is no different whether this is from 20% to 30% or from 60% to 70%. Imposing these restrictions, the equation (2) becomes:

$$q_a = z_a\gamma_0 + \pi_a\delta_1 + \varepsilon_{0a}. \tag{3}$$

One critical point is to control for the correlation between π_a and ε_{0a}. There are two methods for resolving this difficulty.

22. First, the principle of *matching methods* would be to include within z_a all possible variables that might influence the estimation of the relationship between the left hand side of equation (3) and π_a so that once these factors are taken into account, there remains no correlation between the error term ε_{0a} and the propensity score π_a :

$$\varepsilon_{0a} \perp \pi_a \mid z_a. \tag{4}$$

We use a number of such variables including population density, distance to Europe, and geographic coordinates (latitude, longitude and altitude). In principle if we had found all such variables we could estimate equation (3) using the technique of OLS.

23. Secondly, it remains possible that condition (4) will be violated if some *unobserved* heterogeneity in tastes is correlated with factors that also affect the availability of DTT. This would oblige us to use a second method, namely that of instrumental variables. If there exists at least one variable affecting π_a and not the error term ε_{0a}, we can use the method of Two-Stage Least Squares to estimate the relationship between a *predicted* value of DTT availability and subscriptions to Sky's pay TV services. This allows us to test whether condition (4) is indeed violated by our data; essentially we see whether using instrumental variables modifies our estimate of the effect of DTT by more than could be expected by simple chance.

24. Note that the dependent variable is written as a linear function of the propensity score, π_a, so that the Marginal Treatment Effect is defined as above. It is possible in principle that such effects could be non-linear; the general case of non linear functions and the interpretation of IV in this context is analyzed in Heckman and Vytlacil (2007).

25. Furthermore, there could be characteristics of the data that might affect the validity of the tests usually used to test hypotheses in such models, and we use various methods to explore the robustness of our results to such concerns. For instance there could be heteroskedasticity and/or spatial correlation in ε_{0a} which would affect the computation of the correct standard errors. We used the procedure proposed by Conley (1999) to correct standard errors. An auxiliary parameter is the distance at which spatial correlation is significant and we estimate it using spatial correlation tests.

3 Data

26. Our dataset, supplied to us by Sky, consists of information about 2777 postcode districts in the United Kingdom in February 2007 and February 2008. This is equivalent to just under 95% of all postcodes in the UK; we have no reason to believe any bias has been introduced into the results by the incompleteness of the coverage[1].

27. For each postcode district we have the following variables:

    - Number of households (as measured by the number of postal delivery points);
    - Number of subscriptions to Sky basic packages;

[1] Of 2950 postcode districts in the UK, complete data on DTT and cable availability were available for 2826. Discussions with Sky led us to delete 14 postcode areas which are thought to be non geographical areas or which were redesigned in the course of the sample period. Some explanatory variables were missing for 15 areas and subscriber data were unavailable for 20. This left 2777 observations for estimation in the present paper. This number is significantly larger than the number of observations, 2663, used in Sky's study where some outliers were excluded.

- Number of subscriptions to Sky premium packages, and their division into Sports-only, Movies-only and Movies-plus-Sports packages;
- Percentage of households with access to DTT;
- Percentage of households with access to cable;
- Average income;
- Percentage of households living in multi-dwelling units (such households often face restrictions on the erection of satellite dishes);
- Geographical characteristics of the district: latitude, longitude, altitude and distance from continental Europe (to reflect the fact that some transmitters broadcast at low power to avoid signal interference);
- Distance from nearest DTT transmitter;
- Population density;
- Household lifestage, namely membership of one of the following demographic categories:

Lifestage 18-24

Lifestage 25-34, no children under 16

Lifestage 25-34, youngest child 0-4

Lifestage 25-34, youngest child 5-10

Lifestage 25-34, youngest child 11-16

Lifestage 35-54, youngest child 0-4

Lifestage 35-54, youngest child 5-10

Lifestage 35-54, youngest child 11-16

Lifestage 55-64

Lifestage 65-74

Lifestage 75+

Other lifestage.

Subscriptions data are measured separately for February 2007 and February 2008; the remaining variables are measured in 2006. We used the number of delivery points in a postcode as a weighting factor in our descriptive and estimation procedures below.

28. Descriptive statistics for these variables are provided in Table 1. The probability of subscribing to a Sky basic package (only) is [redacted]% in 2008, and has [redacted] between 2007 and 2008 while subscriptions to premium packages amount to [redacted]% of households, [redacted]. Decomposing these premium subscriptions into sports and/or movies packages shows that combined sports-and-movies packages attract [redacted]% of the population while sports only, or movies only, packages respectively attract [redacted]% and [redacted]% of households. The variation of the total take-up of Sky subscriptions across postcode areas is quite significant, minimum values being as low as 0% and maximum values reaching a share of [redacted]% of households. In terms of availability, DTT access is more common (83%) than access to cable TV (50%).

4 Results

4.1 Simple correlation and the inclusion of control variables

29. Tables 2 to 6 report the results of a descriptive analysis of Sky basic and premium subscriptions building up by increments from the analysis of raw correlations to the analysis of the results of multivariate estimation. Table 2 shows that basic and premium subscription rates are strongly and negatively correlated with DTT availability across postcode districts in the UK. Using simple regression tools, Table 3 reports the same qualitative results of a negative relationship between sub-

scriptions and DTT availability (though the estimated parameters are normalized differently). Additionally, this Table shows that these relationships are significantly different from zero as Student t-statistics are much larger than 2.

30. As one would expect, correlations of subscription levels with cable availability in postcode areas are also negative as shown in Table 2. While correlations with DTT or cable availability are of equal magnitude for basic subscriptions, correlations of premium subscription rates with DTT availability is smaller than with cable availability. Note also that in Table 2 cable and DTT availability are positively and strongly correlated. This could suggest that one of the two variables might be a potential proxy, or confounder, for the other. This is why it is important to turn to multivariate analyses where both DTT and cable availability are entered in the regression as determinants of basic and premium subscriptions.

31. Table 4 reports this analysis, confirming previous results and rejecting the suggestion that DTT availability is a confounder for cable availability. Both DTT and cable availability are very significant determinants of both types of subscription, all other things being equal. DTT availability has therefore a negative and significant impact on subscriptions, keeping cable availability constant. There is additional information that can be derived from these results. The impact of DTT availability seems stronger than the impact of cable availability on basic subscriptions while the reverse holds for premium subscriptions. Nevertheless, some other variables, or confounders, such as the composition of the population of the postcode could again explain the tastes for pay TV and availability variables. This is why we use control variables, such as income, the number of collective dwellings, sociodemographics, population density, distance to mainland Europe and geographical coordinates in a full multivariate analysis which is reported in Tables 5 and 6. The qualitative results do not change and if anything, the quantitative results are reinforced since Student t-statistics associated with

the significance test of availability variables for DTT or cable increase when we introduce the controls.

32. The main conclusion of this descriptive analysis is that DTT availability negatively and significantly affects subscription rates for basic and premium Sky packages and that the effect is smaller for premium subscriptions. Furthermore, DTT availability has a larger impact than cable availability on basic subscriptions, although the impact for premium subscriptions is very similar. There is still some doubt whether the treatment variable, DTT availability could be correlated with some unobserved cause of tastes for pay TV across postcode areas. This is why we now turn to our preferred estimation in which we use the method of instrumental variables.

4.2 Controlling for endogeneity

4.2.1 Our preferred specification

33. We estimate the relationship between access to DTT and subscriptions to Sky's pay TV services using Two-Stage Least Squares, with the distance to the nearest transmitter as the instrument for access to DTT. The validity of the instrument cannot be tested using the data and should be argued on prior grounds, although additional instrumental candidates can be tested (see below). The location of DTT transmitters is determined in the first instance by the location of existing analogue TV masts: 80 of the existing 1154 sites are used to broadcast DTT services. The choice of which of the 1154 sites to use was a technical issue of how to reach as many households as possible - for example by selecting masts which cover wide areas. There were also constraints imposed on DTT transmission due to the need to avoid interfering with both analogue terrestrial television services and television services in other countries in continental Europe and Ireland. Given this, it would be surprising if the distance of the centres of postcodes to the transmitter were systematically related to tastes affecting Sky subscriptions. In our

view, there are no compelling arguments to reject the validity of the distance to a transmitter as an instrument.

34. The results of the first stage of the two stage least squares regression are reported in Table 7; this is the prediction of the availability of DTT as a function of the truly exogenous variable Distance to transmitter, as well as of the other determinants of subscriptions. The Student t-statistic of the variable Distance to transmitter has a value of nearly 20, so it qualifies as an extremely strong instrument; the probability that such a correlation is purely due to chance is a tiny fraction of 1%. In other experiments that are not reported here, we verified the robustness of this significance to the inclusion of very detailed geographical information (which consist in splines of the geo-coordinates, latitude and longitude); however, we report below some simpler tests of robustness to the inclusion of geographical variables such as latitude and longitude.

35. As expected, the first-stage regression shows that DTT availability is negatively correlated with the distance to a transmitter. An increase of one standard deviation of this latter variable (.072, see Table 1) decreases the probability of receiving DTT by 8 percentage points. In terms of other major determinants, DTT is also more available in more populated and richer postcode areas where cable is also more likely to be accessible.

36. The main results of interest are presented in Tables 8 and 9. They show the parameter estimates from the second-stage equation which estimates the impact of DTT availability (as predicted by the distance to the transmitter) on subscriptions to Sky's basic and premium packages. This impact is negative and highly significant in both equations. In terms of elasticities, these estimates lead to an elasticity of about −[redacted] (=.83*.082/[redacted]) in the case of Sky basic and −[redacted] (=.83*.059/[redacted]) in the case of premium subscriptions. Cable accessibility also has a negative effect on Sky subscriptions, and this variable is strongly sig-

nificant. The effect is greater for premium than for basic subscriptions. Elasticities are respectively equal to −[redacted](=.50*.048/[redacted]) for basic subscriptions and −[redacted] (=.50*.055/[redacted]) for premium. The results for income variables and demographics are intuitive: higher incomes lead to higher subscriptions; households aged 25-34 with children are more likely to subscribe, and so on.

37. The question remains whether DTT availability is indeed revealed to be an endogenous variable in the estimation, and therefore whether our IV estimations are more justified than standard OLS estimation. We report the results of exogeneity tests at the foot of Tables 8 and 9. The hypothesis of exogeneity is rejected in the premium equation at a level of statistical significance below 1%, but in the basic equation it is rejected at a little over 5%.

38. There are other specification issues that are interesting to explore, and it is to these that we now turn.

    - First, there are other possible instruments for DTT availability.
    - Second, as the data are spatial, spatial correlation could invalidate the standard errors used for hypothesis testing.
    - Third, as information about subscriptions is available over time, we can analyze the stability of the results.
    - Fourth, decomposing premium packages into their constitutive elements could help in understanding why the elasticities for premium packages are smaller than for basic packages.
    - Fifth, there might be omitted geographical factors influencing tastes for pay TV, so we explore whether including various definitions of geographical variables (latitude and longitude) makes any difference to the parameter estimates.
    - Finally, we run our preferred specification again using a subsample where outliers (extreme values) are removed.

4.2.2 Additional instruments

39. Other instruments could be used for DTT availability but overidentifying tests reject their suitability in at least one of the two models of interest for basic and premium subscriptions. Failure to pass the tests of overidentification means that these variables are correlated to the residual tastes that affect household subscription behavior in the population - in other words, it is unjustified to exclude them from the main equation. Population density is one such variable. It positively affects not only DTT availability but also the main dependent variables of interest, basic and premium subscriptions. Its significance in these two equations, even after its indirect impact through DTT availability has been accounted for, makes it an unsuitable instrument.

40. Another such candidate variable is the distance to continental Europe. This seemed to us initially a plausible instrument since regulations on interference between transmitters in different countries affect the installation of transmitters in the UK and therefore DTT availability in their vicinity. It is in the same class of geographical instruments as latitude, longitude and altitude, so that we can analyze these variables as a group. In particular, given that transmitters are more frequently installed in higher spots, altitude might also have been a good candidate as an instrument. Yet, neither distance to Europe nor altitude are good instruments since their validity is rejected, using a Sargan test procedure, in a simple regression where linear controls for latitude and longitude are used.

41. The effect of altitude needs more comment. It is indeed a valid instrument in the basic equation but not the premium equation. Considering altitude as an instrument suggested to us that it might be appropriate to control for location in a very detailed way. It is indeed altitude *relative* to the altitudes of neighboring areas which is a valid instrument, since transmitters are more likely installed in relatively, and not absolutely, higher locations. We attempted to use second-order splines

in latitude and longitude in order to provide such a control. Doing so decreased the significance of the test of the validity of altitude as an instrument, when we performed the control at quite a fine level of geographical detail. The delicate issue that we encountered when using this empirical strategy is that we could not estimate the number of spline terms that should be included in the equation using standard criteria such as Akaike or BIC. It is always significantly better to include more geographical terms.[2] We decided not to pursue this strategy further since the significance of the instruments remains large for any number of geographical terms. In addition, this empirical strategy yields very similar estimates of the coefficient of DTT availability in both equations of interest, although by increasing the standard errors it tends to make the estimated coefficient of DTT availability less significant in the premium equation.

4.3 Other tests of robustness

4.3.1 Spatial correlation

42. Spatial correlation has the same consequences as autocorrelation in time series. In models which are not autoregressive, it does not affect the consistency of estimates, but only their standard errors (Davidson and McKinnon (2004)). We first report in Table 10 Moran tests of spatial correlation using various distance bands. We normalize the variation of latitude and longitude across postcode areas to a square of size 1 so that the UK is contained in the unit square. Moran's spatial correlograms indicate that the correlation is significant and positive until a distance of .3. There is also some indication of negative autocorrelation at higher distances, which is surprising, but this is by no doubt caused by the presence in the regressions of geographical variables, latitude and longitude in particular.

43. Using these results, we corrected spatial correlation in GMM estimation

[2]Our software, Stata, also limited us to 20 nodes in the splines.

as developed by Conley (1999). We assume that the maximum distance for this correlation is .3.[3] Tables 11 and 12 report results both without and with correction. The increase in the magnitude of the standard errors can be quite large - up to a factor of 3 - but more generally lies between 1.5 and 2. It does decrease the statistical significance of our results though not their qualitative nature. DTT and cable availability are still significant negative determinants of subscriptions to Sky's pay TV services.

4.3.2 Robustness over time

44. Table 13 reports results using as dependent variables Sky subscriptions (basic and premium) in 2007 to assess the robustness of our findings over time. These results are corrected for spatial correlation. Our quantitative results are confirmed since the coefficients of DTT and cable availability in Sky basic equations only change by around 5%. Overall, therefore, our estimated elasticities seem highly robust over time.

4.3.3 Decomposition of premium subscriptions into different types

45. We can decompose premium subscriptions into three main types: sports-only, movies-only and sports-and-movies subscriptions. Parameter estimates are reported in Table 14. The effect of DTT availability, although negative, is now no longer significant at 5% (when correcting for spatial correlation) in the equation for sports-plus-movies, though its significance remains quite strong in the single-element packages. Indeed, the elasticity estimates implied by the latter equations are somewhat larger than the overall premium elasticities. This suggests that DTT availability exercises a stronger influence on the single-component subscriptions than on the sports-plus-movies packages. Note that the magnitude of the parameter estimate is similar to that of cable avail-

[3]We did this estimation in Stata using a program available on the Web and written by Jean Paul Dubé at the University of Chicago.

ability in all three equations although the standard errors are higher.

4.3.4 Robustness to other geographical definitions

46. Various different points of latitude and longitude can be used for each postcode district: the geographical coordinates of the administrative center of the postcode area, or of the center of this area in terms of population – i.e. the point which minimizes the sum of squared distances between itself and all households location in the postcode area – or of the geographical center – i.e. the minimizer of the integral of the squared distance between this point and all points in the district. The definition we have used in the main regressions is the distance from the population center. However, to verify the robustness of the results to an alternative definition, Table 15 compares the estimated coefficients for the main variables of interest (availability of Freeview and cable) using the population center and using the geographical center[4]. The estimates when using the two definitions are not significantly different.

4.3.5 Exclusion of outliers (extreme effects)

47. One possible cause for concern in studies of this kind is that outliers may be having an undue weight on the results. There are various ways of testing the robustness of the results to this possibility, and we have chosen the simplest method, which is to drop the observations with the 5% largest positive deviations from the predicted value, as well as those with the 5% largest negative deviations. Table 16 reports the results. Removing these outliers makes very little difference to the parameter estimates, except in the case of sports-and-movies, where the parameter estimate increases by around a quarter, enough to make the impact of Freeview very similar to the impact of cable. (However, given the high variability of sports-and-movies subscriptions between postcodes the estimates are still not statistically significant at conventional 5% levels).

[4]The estimation is performed using the same covariates as before, though these are not reported.

This means that the results we have reported so far are not being disproportionately driven by outliers – on the contrary, in reporting the results that include outliers we are being somewhat conservative in our conclusions. Thus our preferred specification still includes these outliers, but we have verified that if we were to remove them we would have found slightly stronger results.

5 Implications: the impact of Freeview on Sky

48. How big are these numbers, and how important, therefore, is the competitive discipline exercised by DTT availability on Sky? One simple summary answer is that it is greater than the impact of cable availability on all categories of subscription and in all specifications, with the single exception of the combined sports-and-movies premium subscriptions in the specification including outliers. For basic-only subscriptions the effect is around one and a half times that of cable.

49. More precisely, we can compare the coefficients on access to DTT and on access to cable in Tables 8 and 9, which represent our preferred specification for basic and premium subscriptions respectively. For basic subscriptions the coefficient on access to DTT is around 70% greater than that on cable access, while for premium subscriptions the coefficient on DTT access is some 7% greater. Table 16 shows that removing outliers makes virtually no difference to the coefficients on DTT and cable access for basic subscriptions. Removing outliers slightly increases both coefficients for premium subscriptions, though without changing their relative magnitude.

50. Table 14 allows us to compare the coefficients on access to DTT and on access to cable for different types of premium subscriptions, and Table 16 shows the same comparison once outliers are removed. These comparisons indicate that access to DTT has:

- around the same level of impact as cable availability on movies-only subscriptions (although the effect is somewhat stronger once outliers in the data are removed);
- a stronger impact than cable availability on sports-only subscriptions (removing outliers in the data does not significantly alter the estimate of the impact of either service); and
- a weaker impact than cable availability on combined sports-and-movies subscriptions (although the difference in impact between Freeview and cable disappears when outliers in the data are removed).

51. Another way to think about the economic significance of these estimated effects is to estimate what increase in Sky's pay TV prices would generate a reduction in demand for subscriptions equivalent to a given increase in DTT availability; we can interpret this number as in some sense the reduction in the willingness to pay for Sky subscriptions due to the increased availability of DTT. We can estimate this approximately by assuming a constant elasticity of demand in the vicinity of the price change. Let $q = Kp^{-\varepsilon}$ be the demand for Sky's pay TV services for some reference level π of DTT availability and the current price level p. The intervention raising DTT average availability from π to $\pi + \Delta\pi$ turns q into $q - \Delta q$ at the same price p. An equivalent movement in price Δp is defined as:

$$K(p + \Delta p)^{-\varepsilon} = Kp^{-\varepsilon} - \Delta q$$

therefore:

$$(1 + \frac{\Delta p}{p})^{-\varepsilon} = 1 - \frac{\Delta q}{q} \Longrightarrow \frac{\Delta p}{p} = (1 - \frac{\Delta q}{q})^{-1/\varepsilon} - 1 \simeq \frac{1}{\varepsilon}\frac{\Delta q}{q}.$$

52. Suppose that we evaluate, when demand q is equal to the average, the impact of an increase of 20% of DTT penetration i.e. the frequency of DTT availability in a postcode area increases from π to $\pi + 0.2$. Note

that this is approximately equal to the standard deviation of DTT availability which is around 26%. We are looking for an equivalent price variation that would lead to the same fall in demand without any increase in DTT availability. We take low and high values for the demand elasticity from the existing literature to give an idea of the plausible range of variation. Specifically we assume elasticities of 1.5 and 2.5, in line with estimates using microdata in the United States (Goolsbee and Petrin (2004)). Finally, we use the 2008 real average monthly subscription prices for a basic package (respectively for premium) equal to £19.44 (respectively £41.58). We report the equivalent change in willingness to pay in Table 17.

53. What does this tell us about the value of DTT availability to a given household? In other words, can we use these findings to tell us how a typical household's willingness-to-pay for Sky's pay TV services changes when DTT becomes available to that household? A 20% increase in the availability of DTT in a postcode district means that 20% of households have experienced this change in availability, and the resulting fall in demand for Sky subscriptions is entirely concentrated in this 20% subset. We can therefore use the change in demand concentrated in the subset of households experiencing the new availability of DTT as a measure of the change in willingness to pay of households in that subset.

54. To make the point formally, we can use the terms of the model developed in section 2. Let $D_h(=0,1)$ describe whether DTT is available or not to household h in the data. Let also D'_h stand for DTT availability after the intervention that makes households switch. The proportion of households who switch is equal to 20% and households only switch from the state where DTT is not available to a state where DTT is available so that:

$$\Pr(D_h = 0, D'_h = 1) = 20\%, \quad \Pr(D_h = 1, D'_h = 0) = 0.$$

The rest of the population does not switch and their behavior is not affected by the intervention. A consumer satisfying $D_h = 0$ and $D'_h = 1$ is called a treated consumer.

55. Given assumption (1) in paragraph 19, these households are no different on average in their tastes from the remaining households in the district, so that for these households the fall in demand represents a proportionate fall that is five times the proportionate fall calculated for the population of households in the district as a whole (this makes sense given that each affected household is experiencing not a 20% increase in its probability of having access to DTT but a 100% increase). Assumption (1) also implies that these households' demand is exactly as elastic as that of the population as a whole. We can therefore multiply the sums in Table 17 by a factor of 5 to give the equivalent reduction in willingness to pay for a given consumer who experiences a change so that DTT becomes available ($D'_h = 1$) when previously it was not ($D_h = 0$).

56. In summary, we are looking for the change in prices $p \to p + \Delta p$ in the treated population ($D_h = 0, D'_h = 1$), holding constant DTT availability at the initial value D_h, which gives the same change in demand as the intervention $D_h \to D'_h$. This is in contrast with the results of Table 17 which reports the change in prices $p \to p + \Delta p$ in the whole population holding constant DTT availability at the initial value D_h, giving the same change in demand as the intervention $D_h \to D'_h$. Moreover, note that the results of Table 18 are insensitive to the magnitude of the increase (here 20%) of DTT availability while the results in Table 17 vary linearly with the magnitude. In this sense, the results of Table 18 exploit small variations of DTT availability only.

57. These are fairly large numbers, representing changes in willingness to pay of over 10% of the initial subscription price even on the more conservative assumption about elasticities. Do they make sense in the light of other findings in the scientific literature? The closest comparison

is with some studies in the United States that compare the demand for pay TV in regions of the USA with access to different numbers of free-to-air signals (of given quality). See Dertouzos and Wildman (1998), for instance, who compare the availability of different numbers of broadcast channels in different regions of the United States with the prices, subscriber numbers and numbers of channels carried by cable operators. The authors show that the effect of the availability of five or more broadcast channels is to reduce cable subscriptions in broadcast markets by an average of 19%, compared to a base case in which there are fewer than three channels available. These findings are consistent with those reported here, although the study's use of data from the late 1980s might be considered to limit its applicability to the UK in 2008. Goolsbee and Petrin (2004) undertake a study of competition with cable in the USA, but this is competition from pay TV delivered by satellite. The results indicate a significant degree of substitution between different television services.

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Table 1: Descriptive statistics of variables

	Variable	Mean	Std.Dev.	Min	Max
Sky subscriptions (percentage)	basic package in 2007	[redacted]	[redacted]	[redacted]	[redacted]
	premium package in 2007	[redacted]	[redacted]	[redacted]	[redacted]
	basic package in 2008	[redacted]	[redacted]	[redacted]	[redacted]
	premium package in 2008	[redacted]	[redacted]	[redacted]	[redacted]
Sky premium type (percentage)	sports-and-movies in 2008	[redacted]	[redacted]	[redacted]	[redacted]
	sport-only in 2008	[redacted]	[redacted]	[redacted]	[redacted]
	movies-only in 2008	[redacted]	[redacted]	[redacted]	[redacted]
Technology access (percentage)	access to DTT	83.3	26.2	0.0	100.0
	access to cable	50.4	40.0	0.0	100.0
Household characteristics	number of households per district	14547.8	7340.1	10.0	61839.0
	average income (thousand £ per year)	27.913	7.142	12.747	72.454
Household characteristics (percentage)	living in multi-dwelling units	20.3	16.7	0.0	90.6
	lifestage 18-24	6.5	1.1	0.0	20.0
	lifestage 25-34, no child under 16	12.9	3.4	0.0	60.0
	lifestage 25-34, youngest child 0-4	1.6	0.5	0.0	12.5
	lifestage 25-34, youngest child 5-10	2.2	0.8	0.0	9.6
	lifestage 25-34, youngest child 11-16	1.4	0.5	0.0	12.5
	lifestage 35-54, youngest child 0-4	2.4	0.5	0.0	17.6
	lifestage 35-54, youngest child 5-10	4.5	0.8	0.0	18.3
	lifestage 35-54, youngest child 11-16	5.9	1.1	0.0	25.0
	lifestage 55-64	16.4	2.5	0.0	36.8
	lifestage 65-74	10.6	2.3	0.0	28.0
	lifestage 75+	7.5	2.4	0.0	24.0
District geographical characteristics	distance to continental Europe (mi)	193.7	104.7	27.8	598.4
	population density (people per sq.mi/100,000)	0.050	0.054	2.94E-06	0.532
	latitude (population centre)	0.253	0.138	0.000	0.913
	latitude (geographical centre)	0.253	0.138	0.000	0.901
	longitude (population centre)	0.642	0.169	0.000	1.000
	longitude (geographical centre)	0.642	0.169	0.018	0.997
	altitude	0.142	0.112	0.000	1.000
	nearest DTT transmitter distance (mi/100)	0.119	0.072	0.003	0.747
	number of districts	2777			

Note 1: latitude, longitude and altitude are normalized between 0 and 1

Note 2: all summary statistics and parameter estimates in all tables are weighted by the number of delivery points in each postcode district

Table 2: Correlations between main variables of interest

	basic package in 2008	access to DTT	access to cable
basic package in 2008	1		
access to DTT	-0.599	1	
access to cable	-0.577	0.333	1

	premium package in 2008	access to DTT	access to cable
premium package in 2008	1		
access to DTT	-0.278	1	
access to cable	-0.485	0.333	1

Table 3: Regressions of Sky subscriptions on DTT availability

dependent variable	basic package in 2008		premium package in 2008	
regressor	**coefficient**	**std. error**	**Coefficient**	**std. Error**
access to DTT	-0.090 ***	0.002	-0.060 ***	0.004
constant	0.172 ***	0.002	0.252 ***	0.003
N	2777		2777	
adjusted R^2	0.358		0.077	

Significance levels: * 10%; ** 5%; *** 1%

Table 4 : Regressions of Sky subscription on DTT and cable availability

dependent variable	**basic package in 2008**		**premium package in 2008**	
regressor	**coefficient**	**std. error**	**Coefficient**	**std. Error**
access to DTT	-0.068 ***	0.002	-0.028 ***	0.004
access to cable	-0.042 ***	0.001	-0.062 ***	0.002
constant	0.175 ***	0.002	0.257 ***	0.003
N	2777		2777	
adjusted R^2	0.518		0.250	

Significance levels: * 10%; ** 5%; *** 1%

Table 5: OLS Regression of Sky basic subscriptions with all controls

dependent variable	basic package in 2008		
Regressor	**Coefficient**		**std. error**
access to DTT	-0.072	***	0.002
access to cable	-0.050	***	0.001
average income (thousand £ per year)	0.000	*	0.000
living in multi-dwelling units	-0.010	**	0.004
lifestage 18-24	0.022		0.066
lifestage 25-34, no child under 16	-0.341	***	0.055
lifestage 25-34, youngest child 0-4	0.267		0.179
lifestage 25-34, youngest child 5-10	0.948	***	0.169
lifestage 25-34, youngest child 11-16	-1.023	***	0.228
lifestage 35-54, youngest child 0-4	-0.846	***	0.183
lifestage 35-54, youngest child 5-10	0.561	***	0.121
lifestage 35-54, youngest child 11-16	-0.028		0.104
lifestage 55-64	-0.376	***	0.063
lifestage 65-74	0.020		0.076
lifestage 75+	-0.359	***	0.053
population density (people per sq.mi/100,000)	0.091	***	0.013
distance to continental Europe (mi)	-0.000	***	0.000
Latitude (population centre)	0.239	***	0.038
Longitude (population centre)	-0.105	***	0.014
altitude	0.010	**	0.004
Constant	0.374	***	0.029
N	2777		
adjusted R^2	0.660		

Significance levels: * 10%; ** 5%; *** 1%

Table 6: OLS Regression of Sky premium subscriptions with all controls

dependent variable	premium package in 2008		
Regressor	**Coefficient**		**std. error**
access to DTT	-0.033	***	0.003
access to cable	-0.059	***	0.002
average income (thousand £ per year)	0.005	***	0.000
living in multi-dwelling units	-0.025	***	0.006
lifestage 18-24	0.280	***	0.093
lifestage 25-34, no child under 16	0.102		0.078
lifestage 25-34, youngest child 0-4	4.814	***	0.252
lifestage 25-34, youngest child 5-10	-0.137		0.238
lifestage 25-34, youngest child 11-16	-0.590	*	0.321
lifestage 35-54, youngest child 0-4	-2.133	***	0.257
lifestage 35-54, youngest child 5-10	1.095	***	0.170
lifestage 35-54, youngest child 11-16	0.654	***	0.147
lifestage 55-64	0.162	*	0.088
lifestage 65-74	1.049	***	0.107
lifestage 75+	-0.685	***	0.075
population density (people per sq.mi/100,000)	0.032	*	0.019
distance to continental Europe (mi)	0.000		0.000
Latitude (population centre)	-0.069		0.054
Longitude (population centre)	0.047	**	0.019
altitude	-0.034	***	0.006
Constant	-0.118	***	0.040
N	2777		
adjusted R^2	0.675		

Significance levels: * 10%; ** 5%; *** 1%

Table 7: First-stage regression for DTT availability

dependent variable	Availability of DTT		
Regressor	**coefficient**		**std. error**
access to cable	0.116	***	0.013
average income (thousand £ per year)	0.008	***	0.001
living in multi-dwelling units	-0.055		0.042
lifestage 18-24	0.629		0.627
lifestage 25-34, no child under 16	2.128	***	0.521
lifestage 25-34, youngest child 0-4	-0.002		1.694
lifestage 25-34, youngest child 5-10	1.886		1.602
lifestage 25-34, youngest child 11-16	3.211		2.159
lifestage 35-54, youngest child 0-4	-0.765		1.737
lifestage 35-54, youngest child 5-10	4.172	***	1.142
lifestage 35-54, youngest child 11-16	-0.089		0.986
lifestage 55-64	-0.456		0.594
lifestage 65-74	4.563	***	0.712
lifestage 75+	-1.403	***	0.504
population density (people per sq.mi/100,000)	0.416	***	0.127
distance to continental Europe(mi)	-0.002	***	0.001
Latitude (population centre)	1.496	***	0.362
Longitude (population centre)	-0.458	***	0.128
altitude	-0.719	***	0.041
nearest DTT transmitter distance (mi/100)	-1.196	***	0.063
Constant	0.192		0.272
N	2777		
adjusted R^2	0.319		

Significance levels: * 10%; ** 5%; *** 1%

Table 8: Instrumental variable regression of Sky basic subscriptions

dependent variable	basic package in 2008		
Regressor	**coefficient**		**std. error**
access to DTT	-0.082	***	0.006
access to cable	-0.048	***	0.002
average income (thousand £ per year)	0.000	**	0.000
living in multi-dwelling units	-0.011	**	0.005
lifestage 18-24	0.024		0.066
lifestage 25-34, no child under 16	-0.321	***	0.056
lifestage 25-34, youngest child 0-4	0.269		0.179
lifestage 25-34, youngest child 5-10	0.966	***	0.170
lifestage 25-34, youngest child 11-16	-0.994	***	0.229
lifestage 35-54, youngest child 0-4	-0.885	***	0.184
lifestage 35-54, youngest child 5-10	0.611	***	0.124
lifestage 35-54, youngest child 11-16	-0.036		0.104
lifestage 55-64	-0.379	***	0.063
lifestage 65-74	0.061		0.079
lifestage 75+	-0.374	***	0.054
population density (people per sq.mi/100,000)	0.097	***	0.014
distance to continental Europe(mi)	-0.000	***	0.000
Latitude (population centre)	0.246	***	0.038
Longitude (population centre)	-0.108	***	0.014
altitude	0.005		0.005
Constant	0.374	***	0.029
N	2777		
Wu-Hausman F test of endogeneity	3.331 *		
Durbin-Wu-Hausman χ^2 test of endogeneity	3.353 *		

Significance levels: * 10%; ** 5%; *** 1%

Table 9: Instrumental variable regression of Sky premium subscriptions

dependent variable	**premium package in 2008**		
Regressor	**coefficient**		**std. error**
access to DTT	-0.059	***	0.008
access to cable	-0.055	***	0.002
average income (thousand £ per year)	0.005	***	0.000
living in multi-dwelling units	-0.026	***	0.006
lifestage 18-24	0.287	***	0.094
lifestage 25-34, no child under 16	0.154	*	0.080
lifestage 25-34, youngest child 0-4	4.822	***	0.255
lifestage 25-34, youngest child 5-10	-0.090		0.242
lifestage 25-34, youngest child 11-16	-0.513		0.326
lifestage 35-54, youngest child 0-4	-2.239	***	0.262
lifestage 35-54, youngest child 5-10	1.231	***	0.177
lifestage 35-54, youngest child 11-16	0.632	***	0.149
lifestage 55-64	0.154	*	0.089
lifestage 65-74	1.158	***	0.113
lifestage 75+	-0.727	***	0.077
population density (people per sq.mi/100,000)	0.049	**	0.020
distance to continental Europe(mi)	0.000		0.000
latitude (population centre)	-0.051		0.055
longitude (population centre)	0.039	**	0.019
altitude	-0.048	***	0.007
constant	-0.119	***	0.041
N	2777		
Wu-Hausman F test of endogeneity	12.128 ***		
Durbin-Wu-Hausman χ^2 test of endogeneity	12.171 ***		

Significance levels: * 10%; ** 5%; *** 1%

Table 10: Spatial correlation and Moran's I spatial correlogram

	residual of basic package in 2008	residual of premium package in 2008
residual of basic package in 2008	1	
residual of premium package in 2008	0.380	1

	residuals of basic package in 2008				residuals of premium package in 2008			
distance bands	**I**		**std. error**	**p-value**	**I**		**std. error**	**p-value**
(0 – 0.1]	0.161	***	0.002	0.000	0.099	***	0.002	0.002
(0.1 – 0.2]	0.053	***	0.001	0.000	0.013	***	0.001	0.000
(0.2 – 0.3]	0.000		0.001	0.313	0.013	***	0.001	0.000
(0.3 – 0.4]	-0.007		0.001	1.000	-0.009		0.001	1.000
(0.4 – 0.5]	-0.024		0.001	1.000	-0.028		0.001	1.000

Note: residuals refer to Table 8 and 9
Significance levels (1-tail test of H0: rho = 0 vs Ha: rho > 0): * 10%; ** 5%; *** 1%

Table 11: IV Regression of 2008 Sky basic subscriptions with robust standard errors

Regressor	coefficient	2SLS std. error	Spatial GMM std. error
access to DTT	-0.082	0.006	0.011
access to cable	-0.048	0.002	0.006
average income (thousand £ per year)	0.000	0.000	0.000
living in multi-dwelling units	-0.011	0.005	0.012
lifestage 18-24	0.024	0.066	0.116
lifestage 25-34, no child under 16	-0.321	0.056	0.069
lifestage 25-34, youngest child 0-4	0.269	0.179	0.445
lifestage 25-34, youngest child 5-10	0.966	0.170	0.396
lifestage 25-34, youngest child 11-16	-0.994	0.229	0.347
lifestage 35-54, youngest child 0-4	-0.885	0.184	0.218
lifestage 35-54, youngest child 5-10	0.611	0.124	0.171
lifestage 35-54, youngest child 11-16	-0.036	0.104	0.138
lifestage 55-64	-0.379	0.063	0.161
lifestage 65-74	0.061	0.079	0.121
lifestage 75+	-0.374	0.054	0.098
population density (people per sq.mi/100,000)	0.097	0.014	0.019
distance to continental Europe(mi)	-0.000	0.000	0.000
latitude (population centre)	0.246	0.038	0.084
longitude (population centre)	-0.108	0.014	0.034
altitude	0.005	0.005	0.019
constant	0.374	0.029	0.044

Note: GMM standard errors are robust to spatial correlation

Table 12: IV Regression of 2008 Sky premium subscriptions with robust standard errors

Regressor	coefficient	2SLS std. error	Spatial GMM std. error
access to DTT	-0.059	0.002	0.008
access to cable	-0.055	0.008	0.026
average income (thousand £ per year)	0.005	0.000	0.000
living in multi-dwelling units	-0.026	0.006	0.019
lifestage 18-24	0.287	0.094	0.194
lifestage 25-34, no child under 16	0.154	0.080	0.219
lifestage 25-34, youngest child 0-4	4.822	0.255	0.418
lifestage 25-34, youngest child 5-10	-0.090	0.242	0.545
lifestage 25-34, youngest child 11-16	-0.513	0.326	0.522
lifestage 35-54, youngest child 0-4	-2.239	0.262	0.495
lifestage 35-54, youngest child 5-10	1.231	0.177	0.291
lifestage 35-54, youngest child 11-16	0.632	0.149	0.336
lifestage 55-64	0.154	0.089	0.147
lifestage 65-74	1.158	0.113	0.369
lifestage 75+	-0.727	0.077	0.091
population density (people per sq.mi/100,000)	0.049	0.020	0.023
distance to continental Europe(mi)	0.000	0.000	0.000
latitude (population centre)	-0.051	0.055	0.177
longitude (population centre)	0.039	0.019	0.062
altitude	-0.048	0.007	0.019
constant	-0.119	0.041	0.078

Note: GMM standard errors are robust to spatial correlation

Table 13: Robustness of results over time

Regressor	coefficient	2SLS std. error	Spatial GMM std. error
access to DTT	-0.079	0.005	0.009
access to cable	-0.045	0.001	0.005
average income (thousand £ per year)	0.000	0.000	0.000
living in multi-dwelling units	-0.019	0.004	0.010
lifestage 18-24	-0.072	0.060	0.116
lifestage 25-34, no child under 16	-0.307	0.051	0.069
lifestage 25-34, youngest child 0-4	-0.056	0.163	0.359
lifestage 25-34, youngest child 5-10	0.976	0.155	0.343
lifestage 25-34, youngest child 11-16	-0.683	0.209	0.336
lifestage 35-54, youngest child 0-4	-0.650	0.168	0.194
lifestage 35-54, youngest child 5-10	0.469	0.113	0.142
lifestage 35-54, youngest child 11-16	-0.057	0.095	0.112
lifestage 55-64	-0.309	0.057	0.156
lifestage 65-74	0.057	0.072	0.101
lifestage 75+	-0.374	0.049	0.092
population density (people per sq.mi/100,000)	0.090	0.013	0.019
distance to continental Europe(mi)	-0.000	0.000	0.000
latitude (population centre)	0.255	0.035	0.072
longitude (population centre)	-0.109	0.012	0.030
altitude	-0.000	0.005	0.018
constant	0.360	0.026	0.040
dependent variable	**premium package in 2007**		
Regressor	**coefficient**	**2SLS std. error**	**Spatial GMM std. error**
access to DTT	-0.061	0.008	0.027
access to cable	-0.059	0.002	0.008
average income (thousand £ per year)	0.004	0.000	0.000
living in multi-dwelling units	-0.038	0.006	0.017
lifestage 18-24	0.236	0.094	0.181
lifestage 25-34, no child under 16	0.133	0.080	0.203
lifestage 25-34, youngest child 0-4	4.561	0.255	0.376
lifestage 25-34, youngest child 5-10	0.079	0.242	0.528
lifestage 25-34, youngest child 11-16	-0.412	0.326	0.528
lifestage 35-54, youngest child 0-4	-2.135	0.262	0.444
lifestage 35-54, youngest child 5-10	1.249	0.177	0.292
lifestage 35-54, youngest child 11-16	0.627	0.148	0.300
lifestage 55-64	0.159	0.089	0.157
lifestage 65-74	1.147	0.112	0.355
lifestage 75+	-0.768	0.077	0.098
population density (people per sq.mi/100,000)	0.059	0.020	0.024
distance to continental Europe(mi)	0.000	0.000	0.000
latitude (population centre)	-0.045	0.054	0.189
longitude (population centre)	0.042	0.019	0.066
altitude	-0.052	0.007	0.020
constant	-0.052	0.041	0.070

Table 14: Decomposition of premium into simple elements

dependent variable	sports-and-movies in 2008		
Regressor	**coefficient**	**2SLS std. error**	**Spatial GMM std. error**
access to DTT	-0.018	0.006	0.018
access to cable	-0.023	0.002	0.005
average income (thousand £ per year)	0.003	0.000	0.000
living in multi-dwelling units	0.004	0.004	0.011
lifestage 18-24	0.216	0.065	0.158
lifestage 25-34, no child under 16	-0.021	0.055	0.184
lifestage 25-34, youngest child 0-4	3.039	0.177	0.275
lifestage 25-34, youngest child 5-10	-0.337	0.168	0.336
lifestage 25-34, youngest child 11-16	-0.000	0.226	0.382
lifestage 35-54, youngest child 0-4	-1.607	0.182	0.347
lifestage 35-54, youngest child 5-10	0.665	0.123	0.186
lifestage 35-54, youngest child 11-16	0.362	0.103	0.223
lifestage 55-64	0.038	0.062	0.081
lifestage 65-74	0.769	0.078	0.293
lifestage 75+	-0.573	0.053	0.065
population density (people per sq.mi/100,000)	0.010	0.014	0.017
distance to continental Europe(mi)	0.000	0.000	0.000
latitude (population centre)	-0.075	0.038	0.109
longitude (population centre)	0.043	0.013	0.039
altitude	-0.023	0.005	0.013
constant	-0.097	0.028	0.066
dependent variable	**sports-only in 2008**		
Regressor	**coefficient**	**2SLS std. error**	**Spatial GMM std. error**
access to DTT	-0.026	0.002	0.006
access to cable	-0.019	0.001	0.002
average income (thousand £ per year)	0.001	0.000	0.000
living in multi-dwelling units	-0.033	0.002	0.007
lifestage 18-24	0.097	0.029	0.042
lifestage 25-34, no child under 16	0.246	0.024	0.038
lifestage 25-34, youngest child 0-4	0.975	0.077	0.176
lifestage 25-34, youngest child 5-10	-0.065	0.073	0.162
lifestage 25-34, youngest child 11-16	-0.072	0.099	0.135
lifestage 35-54, youngest child 0-4	-0.178	0.080	0.095
lifestage 35-54, youngest child 5-10	0.509	0.054	0.109
lifestage 35-54, youngest child 11-16	0.135	0.045	0.088
lifestage 55-64	0.133	0.027	0.077
lifestage 65-74	0.356	0.034	0.052
lifestage 75+	-0.039	0.023	0.029
population density (people per sq.mi/100,000)	0.030	0.006	0.007
distance to continental Europe(mi)	0.000	0.000	0.000
latitude (population centre)	-0.019	0.017	0.075
longitude (population centre)	0.009	0.006	0.025
altitude	-0.020	0.002	0.005
constant	-0.078	0.012	0.032

Regressor	coefficient	2SLS std. error	Spatial GMM std. error
dependent variable	**movies-only in 2008**		
access to DTT	-0.011	0.001	0.003
access to cable	-0.010	0.000	0.001
average income (thousand £ per year)	0.000	0.000	0.000
living in multi-dwelling units	0.004	0.001	0.002
lifestage 18-24	-0.022	0.016	0.029
lifestage 25-34, no child under 16	-0.048	0.013	0.023
lifestage 25-34, youngest child 0-4	0.706	0.042	0.077
lifestage 25-34, youngest child 5-10	0.324	0.040	0.082
lifestage 25-34, youngest child 11-16	-0.393	0.054	0.071
lifestage 35-54, youngest child 0-4	-0.379	0.043	0.075
lifestage 35-54, youngest child 5-10	0.029	0.029	0.039
lifestage 35-54, youngest child 11-16	0.122	0.025	0.038
lifestage 55-64	0.003	0.015	0.017
lifestage 65-74	0.025	0.019	0.035
lifestage 75+	-0.082	0.013	0.018
population density (people per sq.mi/100,000)	0.001	0.003	0.004
distance to continental Europe(mi)	-0.000	0.000	0.000
latitude (population centre)	0.039	0.009	0.021
longitude (population centre)	-0.012	0.003	0.008
altitude	-0.004	0.001	0.003
constant	0.040	0.007	0.013

Table 15: Robustness to various definitions of geographical variables

dependent variable	basic package in 2008		
Regressor	**coefficient**	**2SLS std. error**	**Spatial GMM std. error**
access to DTT	-0.079	0.005	0.009
access to cable	-0.045	0.001	0.005
latitude (population centre)	0.255	0.035	0.072
longitude (population centre)	-0.109	0.012	0.030
access to DTT	-0.082	0.006	0.011
access to cable	-0.048	0.002	0.006
latitude (geographical centre)	0.216	0.036	0.076
longitude (geographical centre)	-0.098	0.013	0.032
dependent variable	**premium package in 2008**		
Regressor	**coefficient**	**2SLS std. error**	**Spatial GMM std. error**
access to DTT	-0.059	0.008	0.026
access to cable	-0.055	0.002	0.008
latitude (population centre)	-0.051	0.055	0.177
longitude (population centre)	0.039	0.019	0.062
access to DTT	-0.059	0.008	0.026
access to cable	-0.055	0.002	0.008
latitude (geographical centre)	-0.054	0.052	0.164
longitude (geographical centre)	0.041	0.018	0.057

Note: other regressors from previous tables are included in estimations but the coefficients are not reported here

Table 16: Robustness to outliers

dependent variable	basic package in 2008		
Regressor	**coefficient**	**2SLS std. error**	**Spatial GMM std. error**
access to DTT	-0.081	0.005	0.008
access to cable	-0.048	0.001	0.004
average income (thousand £ per year)	0.000	0.000	0.000
living in multi-dwelling units	-0.013	0.004	0.008
lifestage 18-24	-0.044	0.056	0.085
lifestage 25-34, no child under 16	-0.415	0.048	0.049
lifestage 25-34, youngest child 0-4	0.247	0.154	0.234
lifestage 25-34, youngest child 5-10	0.900	0.147	0.263
lifestage 25-34, youngest child 11-16	-1.234	0.197	0.220
lifestage 35-54, youngest child 0-4	-1.039	0.158	0.207
lifestage 35-54, youngest child 5-10	0.487	0.107	0.138
lifestage 35-54, youngest child 11-16	-0.029	0.092	0.125
lifestage 55-64	-0.446	0.054	0.107
lifestage 65-74	-0.055	0.068	0.094
lifestage 75+	-0.358	0.047	0.060
population density (people per sq.mi/100,000)	0.079	0.011	0.016
distance to continental Europe(mi)	-0.000	0.000	0.000
latitude (population centre)	0.215	0.032	0.048
longitude (population centre)	-0.091	0.011	0.022
altitude	0.002	0.004	0.010
constant	0.416	0.025	0.035
dependent variable	**premium package in 2008**		
Regressor	**coefficient**	**2SLS std. error**	**Spatial GMM std. error**
access to DTT	-0.061	0.007	0.017
access to cable	-0.056	0.002	0.006
average income (thousand £ per year)	0.005	0.000	0.000
living in multi-dwelling units	-0.027	0.006	0.014
lifestage 18-24	0.271	0.085	0.172
lifestage 25-34, no child under 16	0.197	0.074	0.169
lifestage 25-34, youngest child 0-4	4.861	0.232	0.271
lifestage 25-34, youngest child 5-10	-0.357	0.218	0.388
lifestage 25-34, youngest child 11-16	0.097	0.299	0.413
lifestage 35-54, youngest child 0-4	-2.340	0.240	0.441
lifestage 35-54, youngest child 5-10	1.286	0.164	0.327
lifestage 35-54, youngest child 11-16	0.676	0.140	0.307
lifestage 55-64	0.112	0.082	0.137
lifestage 65-74	1.275	0.104	0.262
lifestage 75+	-0.691	0.070	0.085
population density (people per sq.mi/100,000)	0.069	0.017	0.018
distance to continental Europe(mi)	0.000	0.000	0.000
latitude (population centre)	-0.002	0.047	0.130
longitude (population centre)	0.018	0.017	0.044
altitude	-0.044	0.006	0.014
constant	-0.128	0.037	0.069

dependent variable	Sports-and-movies in 2008		
Regressor	**coefficient**	**2SLS std. error**	**Spatial GMM std. error**
access to DTT	-0.023	0.005	0.015
access to cable	-0.023	0.001	0.004
average income (thousand £ per year)	0.003	0.000	0.000
living in multi-dwelling units	0.002	0.004	0.010
lifestage 18-24	0.235	0.057	0.137
lifestage 25-34, no child under 16	0.045	0.049	0.138
lifestage 25-34, youngest child 0-4	3.076	0.152	0.199
lifestage 25-34, youngest child 5-10	-0.324	0.145	0.236
lifestage 25-34, youngest child 11-16	0.198	0.199	0.314
lifestage 35-54, youngest child 0-4	-1.741	0.158	0.309
lifestage 35-54, youngest child 5-10	0.711	0.108	0.173
lifestage 35-54, youngest child 11-16	0.431	0.093	0.181
lifestage 55-64	0.060	0.054	0.065
lifestage 65-74	0.798	0.069	0.209
lifestage 75+	-0.482	0.047	0.058
population density (people per sq.mi/100,000)	0.031	0.012	0.014
distance to continental Europe(mi)	0.000	0.000	0.000
latitude (population centre)	-0.054	0.031	0.084
longitude (population centre)	0.031	0.011	0.029
altitude	-0.023	0.004	0.010
constant	-0.122	0.025	0.053
dependent variable	sports-only in 2008		
Regressor	**coefficient**	**2SLS std. error**	**Spatial GMM std. error**
access to DTT	-0.025	0.002	0.004
access to cable	-0.019	0.001	0.001
average income (thousand £ per year)	0.001	0.000	0.000
living in multi-dwelling units	-0.032	0.002	0.005
lifestage 18-24	0.064	0.025	0.038
lifestage 25-34, no child under 16	0.229	0.021	0.030
lifestage 25-34, youngest child 0-4	0.911	0.069	0.149
lifestage 25-34, youngest child 5-10	-0.084	0.063	0.121
lifestage 25-34, youngest child 11-16	-0.106	0.087	0.097
lifestage 35-54, youngest child 0-4	-0.144	0.070	0.097
lifestage 35-54, youngest child 5-10	0.469	0.048	0.095
lifestage 35-54, youngest child 11-16	0.182	0.041	0.093
lifestage 55-64	0.110	0.024	0.049
lifestage 65-74	0.324	0.030	0.047
lifestage 75+	-0.030	0.021	0.023
population density (people per sq.mi/100,000)	0.029	0.005	0.005
distance to continental Europe(mi)	-0.000	0.000	0.000
latitude (population centre)	0.014	0.014	0.051
longitude (population centre)	-0.002	0.005	0.017
altitude	-0.016	0.002	0.003
constant	-0.061	0.011	0.020

dependent variable	movies-only in 2008		
Regressor	**coefficient**	**2SLS std. error**	**Spatial GMM std. error**
access to DTT	-0.010	0.000	0.006
access to cable	-0.010	0.001	0.002
average income (thousand £ per year)	0.000	0.000	0.000
living in multi-dwelling units	-0.004	0.001	0.007
lifestage 18-24	-0.032	0.014	0.024
lifestage 25-34, no child under 16	-0.079	0.012	0.017
lifestage 25-34, youngest child 0-4	0.686	0.039	0.046
lifestage 25-34, youngest child 5-10	0.339	0.036	0.060
lifestage 25-34, youngest child 11-16	-0.459	0.049	0.054
lifestage 35-54, youngest child 0-4	-0.445	0.040	0.047
lifestage 35-54, youngest child 5-10	-0.017	0.027	0.037
lifestage 35-54, youngest child 11-16	0.126	0.023	0.039
lifestage 55-64	-0.027	0.014	0.015
lifestage 65-74	0.020	0.017	0.028
lifestage 75+	-0.104	0.012	0.013
population density (people per sq.mi/100,000)	0.000	0.003	0.003
distance to continental Europe(mi)	0.000	0.000	0.000
latitude (population centre)	0.030	0.008	0.015
longitude (population centre)	-0.009	0.003	0.006
altitude	-0.004	0.001	0.002
constant	0.054	0.006	0.006

Note: top and bottom 5% residuals were dropped, leaving 2501 observations

Table 17: Estimated reductions in average willingness to pay for Sky subscriptions for each 20% increase in DTT availability, low and high elasticities

Subscription Type	Variable		
	Elasticity	$\frac{\Delta p}{p}$	Δp
Basic	-1.5	[redacted]	[redacted]
	-2.5	[redacted]	[redacted]
Premium	-1.5	[redacted]	[redacted]
	-2.5	[redacted]	[redacted]

Table 18: Estimated reductions in average willingness to pay for Sky subscriptions for a representative treated consumer when DTT becomes available, low and high elasticities

Subscription Type	Variable		
	Elasticity	$\frac{\Delta p}{p}$	Δp
Basic	-1.5	[redacted]	[redacted]
	-2.5	[redacted]	[redacted]
Premium	-1.5	[redacted]	[redacted]
	-2.5	[redacted]	[redacted]