dot·econ

International benchmarking of 900MHz and 1800MHz spectrum value

Final Report for Ofcom

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Content

Tables & Figures

Executive Summary

1. Following completion of the 4G auction, Ofcom will revise the Annual Licence Fees (ALFs) applicable to the 900MHz and 1800MHz licences. As directed by the Government it will set ALFs to reflect the full market value of these spectrum bands. [1] In establishing the market value of spectrum in these bands, Ofcom will draw on a wide range of evidence, including evidence on the market value of spectrum in other jurisdictions.

2. Ofcom has commissioned DotEcon to examine various sources of evidence of:

   - prices paid in the primary assignment of spectrum in awards internationally;
   - regulators' market value estimates for the purpose of setting renewal fees for spectrum licences already assigned;
   - the price of spectrum observed in secondary market transactions; and
   - the results of technical and business models published in reports or studies on spectrum value by consultants, regulators, academics, etc.

3. Prices paid in the primary assignment of radio spectrum through an effective and competitive auction process should provide a good indication of market value, with the market clearing price generally being determined by the valuation of the strongest loser. Such prices should reflect the value of the available spectrum in the band that was auctioned.

4. Licence renewal fees set by regulators may often be based on technical and business modelling of spectrum value, and should provide some indication of market value. Similarly, the prices achieved in spectrum trades should provide some indication of market value, although spectrum trades generally cover specific licences and prices are set through bilateral negotiations rather than in a competitive process. In addition, there is often very little transparency in relation to the commercial details of spectrum trades and such trades are often part of more complex deals between buyer and seller. It is therefore difficult to establish prices even where information about the deal is publicly available.

5. There are few 900MHz auctions in Europe that were competitive and would provide good benchmarks for the UK (although they can still be informative, for example in providing a lower bound for the value of spectrum). In 2011 and 2012 Spain, Greece, Portugal, Switzerland, Romania, Ireland and the Netherlands have auctioned off 900MHz spectrum. In Spain, Greece and Portugal, that spectrum was awarded at reserve prices, which suggests that those auctions were not competitive. Switzerland, Romania, Ireland and the Netherlands all auctioned 900MHz spectrum as part of a multi-band award using a "Combinatorial Clock Auction" format. In this format, prices are

[1] The Wireless Telegraphy Act 2006 (Directions to OFCOM) Order 2010 (S.I.2010 No. 3024): http://www.legislation.gov.uk/uksi/2010/3024/contents/made

established only for packages of spectrum lots rather than lots in individual bands, which means that these award processes cannot be used as a primary source of price information for 900MHz value (though they can provide cross-checks).

6. Our analysis includes other spectrum bands that may be of comparable value to 900MHz. Technical and business models we have reviewed suggest that the digital dividend band (700MHz in North American and 800MHz in Europe) should be broadly comparable in value to 900MHz spectrum. Therefore, we expect benchmarks of digital dividend spectrum to be indicative of 900MHz value.

7. Similarly, in order to complement data on 1800MHz valuation, we look at other frequencies that should be of broadly comparable value as suggested by technical modelling. Specifically, we have included benchmarks of 2.1GHz spectrum as a useful cross check to our 1800MHz benchmarks. There is significant overlap in our auction benchmark ranges for 1800MHz and 2.1GHz, with 2.1GHz spectrum achieving a slightly higher price at auction than 1800MHz.

8. Table 1 below presents a summary of our auction prices, market value renewal fees and spectrum trade prices benchmarks.

Table 1: Summary of results

	Spectrum award benchmarks	Renewal fee benchmarks	Spectrum trade benchmarks
900MHz	800MHz: £0.42-£0.74 900MHz: £0.35 - £0.46	800MHz and 900MHz: £0.23-£0.63	US 700MHz: £1.10 - £3.55
1800MHz	1800MHz: £0.21-£0.42 2.1GHz: £0.27-£0.54	1800MHz: £0.12-£0.25 2.1GHz: £0.19	US AWS and AWS-4: £0.21 - £0.53
Relative value of sub-1GHz to 1800MHz	1.5 - 1.9	1 - 5.4	2.3 – 2.8

9. Renewal fees that are likely to reflect market value overlap with the bottom half of our auction benchmarks in the case of 900MHz value. Renewal fees for 1800MHz value are some way lower than our auction benchmarks with only the upper end of the renewal fee range meeting the lower end of the benchmark range.

10. In contrast, our spectrum trade benchmarks of 700MHz spectrum trades in the US suggests a much higher value for sub-1GHz spectrum than our auction benchmark, with the former range exceed the later in its entirety. There is more consistency however when comparing the AWS spectrum trade benchmarks to our 2.1GHz auction benchmarks with the two ranges overlapping to a large extent.

1 Introduction

11. In December 2010 the UK government issued a Direction to Ofcom (the Direction)[2] in relation to, amongst others, the liberalisation of frequencies in the 900MHz and 1800MHz bands. Specifically, the Direction requires Ofcom to set Annual Licence Fees (ALFs) for the 900MHz and 1800MHz licences that reflect the full market value of the frequencies after completion of the 4G auction (see paragraph 10.2 of Ofcom's March 2011 consultation on the 4G auction (March 2011 Consultation[3])). In the March 2011 Consultation, Ofcom notes that full market value of spectrum refers to *"the price that would arise in a well functioning spectrum market"*[4].

12. In setting ALFs that fully reflect the market value of spectrum, Ofcom will draw on a number of inputs, including evidence on the market value of spectrum from other jurisdictions. To this end, Ofcom has commissioned us to examine various sources of evidence that might be used in establishing the value of 900MHz and 1800MHz spectrum and on relative spectrum values across different frequency bands, including:

    - prices paid in the primary assignment of spectrum in awards internationally;
    - regulators' market value estimates for the purpose of setting renewal fees for spectrum licences already assigned;
    - the price of spectrum observed in secondary market transactions; and
    - the results of technical and business models published in reports or studies on spectrum value by consultants, regulators, academics, etc.

13. Prices paid in the primary assignment of radio spectrum through and effective and competitive auction process should provide the clearest indication of market value, with the market clearing price generally being determined by the valuation of the strongest loser. Prices achieved in auctions should be informative of spectrum value across the available spectrum in the band that was auctioned, and auction benchmarks should therefore provide the most reliable guidance in terms of establishing the market value of spectrum.

14. By contrast, spectrum trades generally cover specific licences. If licences were traded bilaterally, the price achieved will lie somewhere between the seller's valuation of spectrum (which provides the appropriate measure of opportunity cost in this case) and the buyer's valuation. The split of the gains from trade is determined by the parties' relative bargaining position – if supply were

[2] The Wireless Telegraphy Act 2006 (Directions to OFCOM) Order 2010 (S.I.2010 No. 3024): http://www.legislation.gov.uk/uksi/2010/3024/contents/made

[3] Ofcom, March 2011, Consultation on assessment of future mobile competition and proposals for the award of 800MHz and 2.6GHz spectrum and related issues.

[4] Paragraph 10.3 of the March 2011 Consultation, ibid.

competitive, the price would be determined by the seller's valuation, but with bilateral negotiations would tend to lie above. One might therefore expect to see higher prices in spectrum trades than in auctions.

15. Licence renewal fees set by regulators may often be based on technical and business modelling of spectrum value. Such models will typically be aimed at establishing a specific operator's value of spectrum, which could in turn be reflected in that operator's maximum willingness to pay in an auction. These valuations may be higher or lower than the prices achieved in an auction. In an auction with effective competition and strong incentives for truthful bidding, it should be the willingness to pay of the strongest loser that ultimately determines final prices in the auction. In any case, it is common for regulators to be more conservative when setting renewal fees, and therefore we would expect these fees to be lower than the auction benchmarks.

16. This report sets out our findings. They are predominantly based on our analysis of data from auctions of radio spectrum in the 900MHz and 1800MHz bands, and in comparable frequency bands. Data from spectrum trades, market value reflecting renewal fees and valuations from technical or business modelling is presented to provide cross-checks for auction benchmarks.

17. In Section 2 we will look at the available spectrum award benchmarks across a number of mobile frequency bands. Unfortunately, direct benchmarks for spectrum in the 900MHz and 1800MHz bands are not easily available. In the case of the primary assignment of 900MHz spectrum, and to a lesser extent 1800MHz spectrum, auctions were not commonly used, particularly in Europe. Most of Europe including the UK, rather than auctioning it off, administratively assigned 900MHz spectrum. Therefore, the number of useful and informative auction benchmarks of 900MHz spectrum is limited, and it is necessary to widen the sample to include other, sufficiently comparable mobile frequency bands. Specifically, we look at the digital dividend bands (800MHz in Europe, and 700MHz outside Europe), the 2.1GHz band and the 2.6GHz band in addition to the 900MHz and 1800Mhz bands.

18. In Section 3 we will look at case studies on licence renewal fees that might be regarded as being reflective of market value. Full case studies can be found in Annex B.

19. Section 4 presents available benchmarks of spectrum prices from secondary market transactions.

20. Finally, Section 5 concludes with an overview and comparison of our auction benchmarks against the other sources of evidence.

21. In collecting evidence that might be of help to Ofcom in establishing the market value of 900MHz and 1800MHz spectrum in the UK, we have endeavoured to be as comprehensive as possible. However, we recognise that the international benchmark values of 900MHz and 1800MHz spectrum included in this report may not be exhaustive. Nonetheless, we are confident that the evidence collected provides a rounded view of the market value of 900MHz and 1800MHz spectrum. Where we have presented any relevant material produced by third parties, we have endeavoured to present these findings in a factual manner. Any views expressed in this report are those of DotEcon.

2 Spectrum award benchmarks

22. In this section we present our benchmarking analysis for estimating the value of 900MHz and 1800MHz spectrum.

23. Prior to 2011, only a handful of countries have auctioned off 900MHz spectrum. Most of these auctions were either uncompetitive and 900MHz spectrum was awarded at reserve, or they comprised only a small amount of 900MHz spectrum.

24. In 2011 and 2012 Spain, Greece, Portugal, Switzerland, Romania, Ireland and the Netherlands have auctioned off 900MHz spectrum. However, in Spain, Greece and Portugal that spectrum was awarded at reserve prices, suggesting that the auction was not competitive and that the benchmark should be interpreted as a lower bound to the value of spectrum. Switzerland, Romania, Ireland and the Netherlands all auctioned 900MHz spectrum as part of a multi-band award using a "Combinatorial Clock Auction" format. In this format, prices will be established only for packages of spectrum lots rather than lots in individual bands, which means that these award processes cannot be used as a primary source of price information (though they provide valuable cross-checks). Therefore, suitable auction benchmarks for 900MHz value are in limited supply, and we will need to consider auction values achieved for spectrum in other bands. The limited number of data points is less of an issue in the case of 1800MHz as there have been more 1800MHz auctions. However, we consider that drawing on a wider sample of mobile frequency bands is likely to yield more robust estimates of both 900MHz and 1800MHz value.

25. For reasons explored in more detail in Annex C, the digital dividend band (800MHz in Europe, and 700MHz in the US) may be considered to be of reasonably similar value to the 900MHz band. Similarly, the 2.1GHz band and paired spectrum in the 2.6GHz band reasonably substitutable for 1800MHz spectrum rand may offer potential benchmarks for comparison.

26. Section 2.1 discusses the underlying data and how we identified suitable benchmarks for market value in the UK. Section 2.2 presents band-specific benchmarks for the 700MHz, 800MHz, 900MHz, 1800MHz, 2.1GHz and the 2.6GHz bands. Section 2.3 uses the results from various Combinatorial Clock Auctions (CCAs) in Europe as a cross-check on the band-specific benchmarks, and Section 2.4 discusses additional benchmarks of relative band values.

2.1 Data used

27. We use spectrum awards data from our in-house Spectrum Awards Database (SAD) in our benchmarking analysis. Our database includes information on 305 award processes across 61 countries worldwide, covering 12,467 licences. We use country specific economic and demographic data from the World Bank's *World Development Indicators* (WDI) database. As only information up

to 2011 was available at the time of performing the benchmarking analysis[5], we have extrapolated data for 2012 and 2013 and interpolated any missing data prior to 2011.

28. In the remainder of this section we describe our data treatment (adjusting for inflation, differences in licence duration and prices in different currencies), and the approaches we have used to identify outliers in those cases where we perform statistical analyses on large samples and to exclude observations in small samples where such analysis is infeasible and we consider each award individually.

2.1.1 Data treatment

29. We have included annual fees in our licence prices where applicable and where the relevant information is available. Specifically, a licence price is calculated as the sum of upfront payments (normally the auction price, plus any administrative fees, where applicable) and the discounted stream of annual fees over the life of the licence. As in our report for Ofcom on estimating the value of 800MHz, 1800MHz and 2.6GHz spectrum (referred to below as "Spectrum Value Report 2012")[6], we use a nominal weighted average cost of capital (WACC) of 8.86% as the discount rate.[7]

30. In our analysis, we also present the minimum price of licences. This is the minimum net present value amount a licensee would have to pay for the licence if acquired at reserve price. Minimum prices of licences are calculated in a similar manner to licence prices, using the reserve price set for the auction and the discounted stream of the annual fees over the life of the licence where such fees are being charged.

31. We have corrected for differences in licence duration terms so that all licence prices are that for a common 20-year term basis and express all prices in GBP at 2013 prices. The conversion of the price data from the different awards into a common currency and the adjustment for differences in licence terms and inflation has been done as follows:

    - Adjustments were made for differing licence terms within the sample (converting prices into equivalent values for a 20-year licence term). Our adjustment for licence duration is based on the NPV calculation of the

[5] We note that the World Bank has subsequently updated its WDI database to include information up to 2012.

[6] DotEcon and Aetha Consulting, 2012, *Spectrum value of 800MHz, 1800MHz and 2.6GHz*, prepared for Ofcom. Available at: http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/statement/spectrum-value.pdf

[7] In our Spectrum Value Report 2012, we noted that it would be preferable to use the operator-specific and country-specific WACC in order to calculate the discounted stream of annual fees. Such information however is not generally available, so we have used the nominal WACC that corresponds to the real pre-tax WACC used in Ofcom's 2011 Mobile Call Termination cost model of 6.2%.

licence value assuming an equal monthly profit stream[8] (π; see Figure 1 below for detailed calculation), using a nominal WACC of 8.86% as our discount rate.

- Purchasing Power Parity data from the WDI database is based in United States Dollars (USD). Licence prices in local currency are therefore converted into a common currency (USD) using Purchasing Power Parity (PPP) exchange rates to account for price differences and levels of affluence between countries (this expresses prices in nominal USD terms).
- Prices in nominal US dollars were adjusted for USD inflation using CPI[9] data, converting prices to USD in 2013 terms.
- Finally, all prices were converted into GBP using a USD/GBP PPP rate for 2013 extrapolated from historical PPP rates. Specifically, we apply a PPP rate of 1 USD to 0.6593 GBP.

32. All prices are then converted into per MHz per capita figures for ease of comparison across different countries and licence sizes.

33. In Annex D, we also present the results based on the corresponding real post-tax WACC of 4.1%.

[8] We consider monthly rather than annual profit streams because some licences in our sample have durations that are not in whole years.

[9] CPI is a general measure of inflation in an economy. Using CPI to adjust licence prices to real terms will therefore reflect present day value of money. We note that CPI has been used by regulators in other jurisdictions to adjust annual spectrum fees to real terms, including in Ireland, USA, Australia and Sweden. This has been documented in Section 4.2.1 of ComReg document 11/29 - *"Interim licences for the 900MHz band"*, available at: http://www.comreg.ie/_fileupload/publications/ComReg1129.pdf

Figure 1: Licence duration adjustment

A licence with duration D months has the following net present value:

$$\text{LicenceFee}_D = \pi \times \sum_{t=0}^{\text{D}-1} \left(\frac{1}{1+8.86\%}\right)^{t/12}$$

Therefore, the monthly profit stream can be calculated as:

$$\pi = \text{LicenceFee}_{\text{D}} \Big/ \sum_{t=0}^{D-1} \left(\frac{1}{1+8.86\%}\right)^{t/12}$$

The value of a licence with a term of *D* can be converted into a 20-year term (240 months) as follows:

$$\text{LicenceFee}_{20\text{ year term}} = \pi \times \sum_{t=0}^{239} \left(\frac{1}{1+8.86\%}\right)^{t/12}$$

$$= \text{LicenceFee}_D \times \sum_{t=0}^{239} \left(\frac{1}{1+8.86\%}\right)^{t/12} \Big/ \sum_{t=0}^{D-1} \left(\frac{1}{1+8.86\%}\right)^{t/12}$$

2.1.2 Selection of observations in small samples

34. The aim of our analysis of auction prices in other countries is to provide estimates of value that provide a good indication of the market value of spectrum in the UK. This means that we would ideally want to focus on data from effectively competitive auction processes where the spectrum on offer was subject to similar licence conditions and where the economic and demographic factors that have an impact on spectrum valuation (such as income, size of the addressable market, the level of competition amongst mobile operators, population density etc.) are broadly comparable to that of the UK.[10]

Competitiveness of the award process

35. Auction prices are a good indicator of market clearing prices where competition is effective and prices are determined by the valuation of the strongest loser. Auctions where competition is weak and the prices that are ultimately paid are close to reserve may not provide a particularly reliable indication of market value (unless reserve prices themselves have already been

[10] Although it is in principle possible to adjust spectrum value estimates for differences in any of these dimensions, making such adjustments requires a sufficiently accurate quantification of the impact that these differences will have on valuation, which is difficult to estimate in practice. We will therefore focus as much as possible on comparable awards.

set with reference to market value, potentially in anticipation of weak competition).

36. Final auction prices being in excess of reserve prices suggest some competition in the auction, but do not in themselves guarantee that the award process was effective in discovering the market value of spectrum. Consideration needs to be given to the different bidding incentives presented by different auction formats.

37. For example, Simultaneous Multiple Round Ascending (SMRA) auctions provide individual prices for specific lots and are thus an accessible source of data for band-specific benchmarks even in the case where spectrum in multiple bands was auctioned in a single award. However, the format suffers from stronger incentives for reducing demand in order to keep prices from increasing than Combinatorial Clock Auctions (CCAs) with their second price rule. We also noted in our Spectrum Value Report 2012 that bidders might face severe aggregation risks in an SMRA format, which may lead them to bid conservatively.[11] Therefore in an SMRA auction, final auction prices may not provide a good indication of market value if competition within the auction was limited or aggregation risks were substantial.

38. By contrast, the CCA format that has been used in a number of recent awards reduces the incentives for reducing demand in order to keep prices down. Bidders have good incentives to compete for incremental spectrum because this does not increase the price they pay for the frequencies they eventually win, but determines opportunity cost for other bidders. Aggregation risks are absent. This means that the prices paid in CCAs should in principle provide a good indication of market value. However, where bid data is not published, the CCA format makes it difficult, if not impossible, to attribute the prices paid for packages of spectrum lots to individual lots. This means that such multi-band CCAs cannot provide a primary source of data for band-specific auction prices, and can only be used as a cross-check on the band specific benchmark estimates that have been obtained from other awards.

39. We will therefore consider the level of competitiveness when considering the suitability of specific award data for inclusion in our analysis. Without competition, licences will sell at reserve, we will therefore consider auctions to be uncompetitive where all lots in a band sell at reserve. Conversely, where prices exceed reserve there was some competition, but this does not necessarily imply that the process was fully competitive. A significant premium of licence prices over reserve prices may indicate strong competition, but even this is an imperfect measure. Trivial reserve prices for instance may attract relatively large premiums over reserve despite modest licence prices that have been set under a moderately competitive environment. On the other hand, a significant reserve price set close to market value may consequently attract relatively low premiums over reserve (if any), even if the auction was competitive.

40. Despite these qualifications, we use the premium over reserve as a first screen for identifying competitive auctions in our analysis. In instances where there is some reason to doubt that premiums over reserve capture auction competitiveness, we will look at other measures such as the ratio of winners to bidders and the value of bids submitted. In some cases, there may be more bidders than winners but the losing bidders may not impose a strong constraint. In such circumstances, a low or trivial winning bid for a licence would suggest that the losing bidder has not posed much competitive pressure on the winners and hence the auction may not be competitive despite there being more bidders than winners.

Market value reflecting reserve prices

41. As discussed above, in auctions where reserve prices are substantial and potentially reflect market value, final prices may not exceed reserve prices by much (or not at all). Such auctions may still provide an indication of the market value of spectrum to the extent that reserve prices reflect market value, and we use the reserve prices for these awards where we can establish that regulators have aimed to set reserve prices with reference to the market value of spectrum.

42. When setting reserve prices, regulators may try to gauge the market value of spectrum through a number of means including business modelling or benchmarking of auction results. Ofcom in the UK and ComReg in Ireland, for instance have published reports with such analyses.[12] Depending on their objectives and their assessment of the conditions for the award, regulators may then set reserve prices close to market value. For instance, where there are significant concerns about weak competition in the auction, the regulator may opt for a higher reserve price; by contrast, if the objective is to encourage participation in the auction then a more moderate reserve price may be set.

43. Setting reserve prices above market value will choke off efficient demand for spectrum and result in an inefficient allocation. Therefore, regulators will generally be cautious when setting high reserve prices with reference to market value, and often use the lower end of their market value estimates as a reference point. ComReg for instance set a reserve price in the lower half of their market value benchmark range[13] while in the Netherlands, the reserve price of 800MHz was set at a third of market value estimates for this band[14]. We expect reserve prices in such cases to provide a lower bound estimate of full market value.

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[12] For the Ofcom study, see: http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/statement/spectrum-value.pdf; the ComReg study is available at https://www.comreg.ie/_fileupload/publications/ComReg1223.pdf

[13] See Section 4.8.5 of ComReg Consultation and Decision, *Multi-band Spectrum Release, Release of 800MHz, 900MHz and 1800MHz Radio Spectrum Bands*, 16/03/2012 available at: https://www.comreg.ie/_fileupload/publications/ComReg1225.pdf (access 10 May 2013)

[14] See Section 5.3.1 of the Ministry of Economic Affairs Regulation (WJZ/10146523),*Regulation regarding the application and safety procedure for 800, 900 and 1800MHz licences*, 06/01/2012

44. Where spectrum remains unsold for reasons other than constraints that may have limited bidders in their ability to acquire spectrum (e.g. reservations or caps), reserve prices may have been set above market value. In these cases, they could be interpreted as an upper bound on market value.

Licence conditions and other factors

45. Licence conditions or the type and amount of spectrum auctioned however, could also impact spectrum value. Onerous licence conditions that increase the roll out or operational cost of operators for instance would necessarily have a negative impact on licence prices.

46. Auctions where only small amounts of spectrum are auctioned are more likely to provide an indication of the incremental value of spectrum for operators who already have a workable spectrum portfolio rather than the total value of spectrum in a band.

47. Where such licence or other auction conditions are likely to have a major impact on the price of spectrum achieved in a particular award, it may be appropriate to exclude such price data from our analysis.

Economic and demographic factors

48. Table 2 below presents some economic, demographic and market data for a number of European countries of comparable size to the UK as well as the US. Germany, France, Italy and to a lesser extent Spain, have comparable economic and mobile market conditions to that of the UK and might therefore be considered as reasonably good comparators. In contrast, the US has a substantially lower population density, a significantly higher GDP per capita, and a substantially higher ARPU than the UK and the other European countries. Whilst the latter two factors might suggest higher spectrum values in the US, the lower population density may imply higher roll out cost and reduce spectrum values.

Table 2: Economic, demographic and market data of large European countries and the US

	UK	Italy	Germany	France	Spain	US
GDP per capita	£24,500	£21,760	£25,900	£23,522	£21,938	£32,500
Population (million)	62.6	60.8	81.7	65.4	46.2	311.6
Population Density (pop/sq km)	259	207	235	119	93	34
Number of operators	4	4	4	4	4	4 national operators
Mobile penetration	129.80%	157.60%	140.20%	104.40 %	125.40%	102.60%
ARPU (monthly)	£15.40	£11.10	£14.90	£21.90	£16.70	£28.30

All data for 2011
Sources: GDP per capita, population, population density - WDI database, number of operators – DotEcon from GSMA, mobile penetration and ARPU from Ofcom ICMR 2012[15]

49. Given the similarity in economic and demographic conditions of the large European countries to the UK, operators' valuations for spectrum in these countries should be comparable to the value of spectrum to operators in the UK.

50. Economic and market conditions at the time of the auction would also influence the quality of the benchmark. Naturally, the more recent spectrum auctions should provide a better indication of market value at present than auctions that took place around the time of the telecoms bubble in 2000/2001, for example. The amounts raised in the UK and German 3G auctions, for instance, are clearly of little relevance for assessing the value of mobile spectrum in 2013.

51. Subject to having being competitive, and having offered a sufficient amount of spectrum without undue restrictions or onerous licence conditions, results from more recent awards in these large European countries should be a prime source of information about comparable spectrum values, and we will place more weight on these awards in our analysis

2.1.3 Selection of observations in large samples

52. It is common for real world data sets to contain outliers, and our sample of spectrum award prices is no different. An outlier is an extreme value in a data sample that is far removed from the rest of the observations in the sample. There are typically good reasons why outliers occur. In the case of spectrum auction prices, specific circumstances surrounding the auction may lead to unusually low or high prices (as discussed above). Some of the early 3G auctions around the time of the telecoms bubble for instance produced prices

that are exceptionally high. Such outliers would not be representative of market value of spectrum, and including them in data analysis may skew results and conclusions. We therefore aim to remove outliers from our dataset. We will use non-parametric methods to identify outliers in our sample that are 'far' removed from the majority of observations.[16]

53. One such common method is to identify outliers through the use of a box plot.[17] A box plot[18] is a representation of data in quartiles (see Figure 2 below). The "box" is framed by the lower and upper quartiles (25th and 75th percentiles respectively) so that the length of the box gives the interquartile range. The median is represented by the solid line through the box. The whiskers extending out from the box end at lower and upper adjacent values. The upper adjacent value is the largest data value that is less than or equal to the third quartile plus one and a half times the interquartile range. The lower adjacent value is the smallest data value that is greater than or equal to the first quartile minus one and a half times the interquartile range. The "inner fence" marks one and a half times the interquartile range from the lower and upper quartiles. The upper fence marks three times the interquartile range (i.e. the distance between the lower and upper quartile).[19] An observation is considered a mild outlier if it lies beyond the inner fence, and an extreme outlier if it lies beyond the outer fence. We refer to this method of identifying outliers as Box Plot Method in our analysis below.

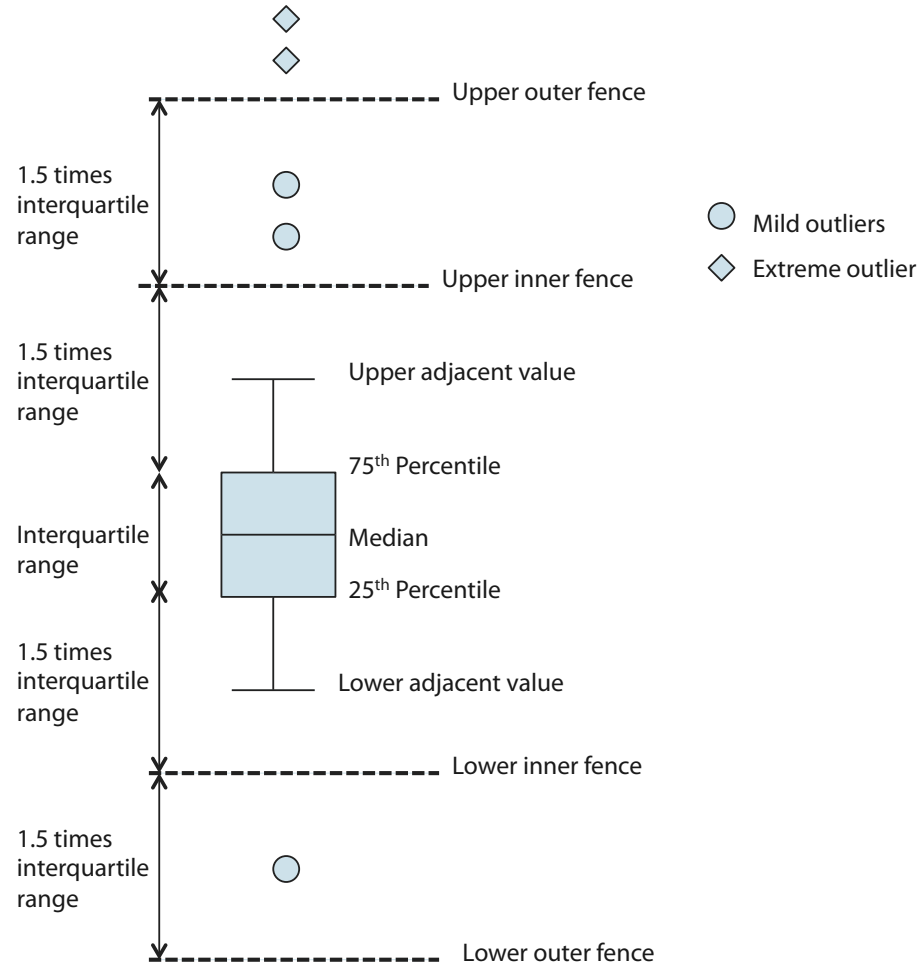
[16] For a more detailed discussion see S Soo, 2006, A Review and Comparison of Methods for Detecting Outliers in Univariate Data Sets", University of Pittsburgh.

[17] See Chapter 3 of Rand R. Wilcox, "Fundamentals of Modern Statistical Methods, Substantially Improving Power and Accuracy", Second Edition.

[18] See Tukey, J.W. (1977), "Exploratory data analysis." Addison-Wesely.

[19] We note that these boundaries are somewhat arbitrary. Frigge et al (1989), for example, propose to define the inner fence based on twice the interquartile range, though keeping the outer fence at three times the interquartile range; see Frigge et al. (1989), "Some Implementations of the Boxplot." The American Statistician, Vol. 43, No. 1 (Feb., 1989), pp. 50-54.

Figure 2: A Box Plot



54. Another method for identifying outliers is to measure an observation's distance from the mean and compare this to a multiple of the standard deviation. Typically, an observation is considered an outlier if it lies beyond two to three times the standard deviation from the mean. In our analysis below, we will consider an observation an outlier if it lies more than three standard deviations from the mean. We refer to this as Standard Deviation Method in our analysis below.

55. Sample mean and standard deviation however may be skewed by extreme values. This means that an outlier may be masked by the presence of another extreme value when identified using the sample mean and standard deviation. In comparison, using sample statistics that are less prone to skewing by extreme values will avoid this issue.

56. One such method is to identify observations as outliers if the observation deviates disproportionately from the median. Specifically, the observations' absolute deviation from the median is calculated and an observation is considered an outlier if its deviation is more than five times the median of the

absolute deviations.[20] We refer to this as the Median Absolute Deviation Method in our analysis below.

57. Outliers identified by these methods may overlap in some instances though these methods may also identify different sets of observations as outliers. In our analysis in Section 2.2.4 and 2.2.5 below, we apply all three methods to our 1800MHz and 2.1GHz samples. We will consider observations identified by all three methods as outliers.

2.2 Band specific benchmarks

58. In this subsection, we present benchmarks for the 900MHz, 800MHz, 700MHz, 1800MHz, 2.1GHz and 2.6GHz bands in turn. Average auction prices presented in our analysis below are simple band specific auction averages, i.e. the average per MHz per capita price of all licences in the respective frequency band that were sold in the auction.

59. As noted above, lot specific licence conditions such as usage restrictions or coverage obligation may depress licence prices. Therefore, the average price of lots across bands may understate true market value of spectrum in the UK if some of the lots sold were subject to much stronger restrictions than would apply in the UK (and overstate market value in the UK if restrictions were less severe). Ideally, such differences should be controlled for, but our spectrum awards database does not contain the necessary information on specific licence conditions.

60. However, we note that in our sample (considering national licences only) the difference between individual licence prices and average prices for spectrum in the same band and in the same auction is on average approximately 10%. This would suggest that on average licence prices of specific lots within a band do not vary too much. Nonetheless, where we are aware of particularly onerous licence conditions that may have a significant impact on spectrum value, we will raise this and analyse this qualitatively.

61. A full list of auctions and awards mentioned in this section is presented in Annex A.

2.2.1 900MHz Auctions

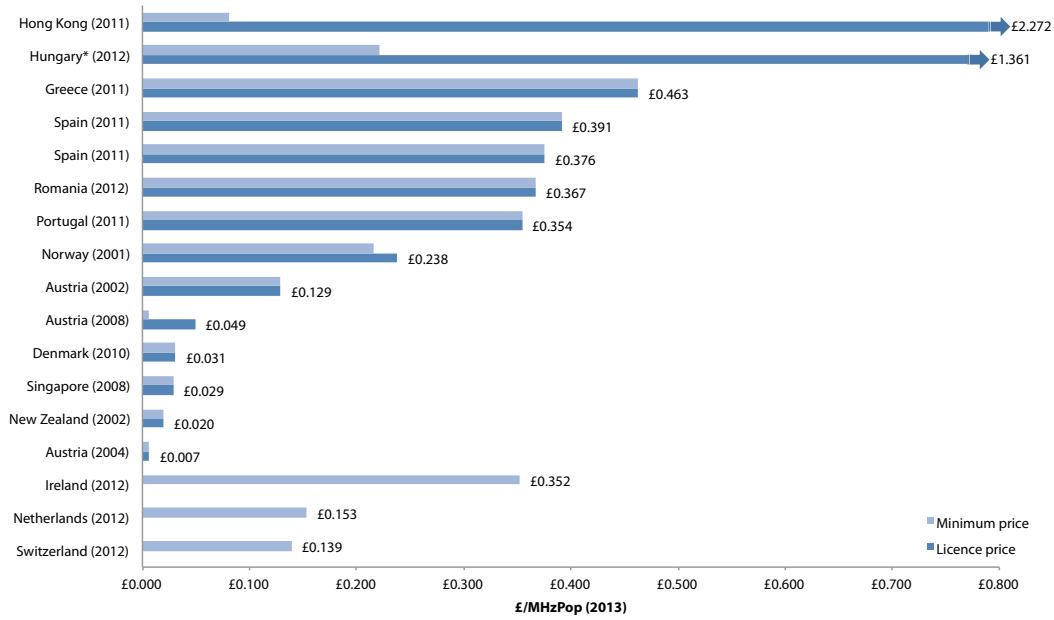
62. Figure 3 below shows the average price achieved in 900MHz auctions, presented in descending order of licence prices achieved. Reserve prices of 900MHz sold in CCAs (Ireland, the Netherlands and Switzerland) have also been included at the bottom. While we cannot establish the specific price paid for 900MHz in these countries owing to the fact that prices were calculated for packages, the reserve prices in these auctions might provide some indication of the minimum value that bidders were prepared to pay for this spectrum.

[20] See Sprent, P. (1993), "Applied nonparametric statistical methods", Chapman and Hall; Iglewicz, B., Hoaglin, D. (1993) "How to detect and handle outliers." ASQC Quality Press; High, Robin. (2000). "Dealing with 'Outliers:' How to Maintain Your Data's Integrity". Computing News, University of Oregon. Available at: http://rfd.uoregon.edu/files/rfd/StatisticalResources/outl.txt.

Although in these awards the requirement that bidders had to pay at least reserve were applied at the level of packages rather than for individual lots, and therefore band-specific reserve prices need to be interpreted with caution, the prices eventually paid were above reserve, and spectrum in this band is likely to have been considered a main source of value. All available spectrum in the 900MHz band was allocated in the Irish, Dutch and Swiss auctions.

63. The Hungarian auction has been annulled because of procedural problems in relation to the ability of firms in public ownership being allowed to bid for the licences.

Figure 3: 900MHz auction average price



*Licences annulled

64. 900MHz average licence prices range from £0.01 to £2.27. There was no competition for 900MHz in several of the European auctions including in Greece, Spain, Romania, Portugal, Austria in 2002 and 2004 and Denmark. In these auctions, 900MHz spectrum was awarded at reserve prices. Outside of Europe, there was also little competition for 900MHz spectrum in New Zealand and Singapore with spectrum selling at reserve as well in these auctions.

65. In Denmark, 2x5MHz of re-farmed spectrum was auctioned with the three incumbents with 900MHz holdings barred from participating in the auction. There are four mobile operators in the Danish market. No new entrant bid for the spectrum hence fourth player Hi3G (who had no 900MHz spectrum) won the lot at reserve price.

66. Reserve prices for 900MHz spectrum that sold at reserve in recent European auctions were set within a relatively narrow range from £0.35 to £0.46. In

Greece, EETT set reserve price based on ComReg's published spectrum benchmark results[21]. We noted above that reserve prices in Ireland were set to reflect market value (see Section 2.1.2). This would suggest that reserve prices in Greece and Ireland both reflect market value. In Netherlands, reserve prices were set at roughly a third of estimated market value[22], which would in turn suggest a market value estimate of £0.46.

67. In Romania, ANCOM considered outcomes from other spectrum auctions, spectrum demand and the physical characteristics of the various bands amongst other factors when setting reserve prices. There was however, no specific reference to reserve prices reflecting market value. For the remainder of auctions where spectrum was allocated at reserve (Portugal, Spain, Denmark, Singapore, New Zealand and the 2002 and 2004 Austrian auctions), there is no indication that reserve prices were set to reflect market value. We note however that reserve prices in Spain and Portugal were similar to those in Ireland where reserve prices were set to reflect market value (and the auctions took place in the same year).

68. In both Spain (first multiband auction) and Portugal, one lot of 2x5MHz[23] went unsold.

- Bidders in the first Spanish multiband auction faced a tight 2x20MHz sub-1GHz cap that took into account existing spectrum holdings. Due to their existing spectrum holdings in the 900MHz band, the spectrum cap limited Orange and Vodafone to bidding for at most 2x10MHz of sub-1GHz spectrum, and Telefónica to 2x15MHz. This meant a maximum demand from these bidders of 2x35MHz for sub-1GHz spectrum, compared with aggregate supply of 2x39.8MHz. As a result, one lot in the 900MHz band remained unsold. This unsold lot was re-auctioned and subsequently acquired by Telefonica at reserve price as the sub-1GHz spectrum cap was relaxed.
- In Portugal, two lots of 900MHz were available in the auction: 880-885MHz paired with 925-930MHz and 885-890MHz paired with 930-935MHz. Operators with existing 900MHz holdings were restricted to bidding for just one 2x5MHz lot. All three existing operators had approximately 2x8MHz of 900MHz spectrum prior to the multiband auction. Given the that the lots in the auction were adjacent to Vodafone

[21] See Section 3.4 of EETT Consultation Document, *Liberalization of the use of 900MHz and 1800MHz spectrum bands and assignment of the relevant rights of use*, January 2011.

[22] The reserve price for 800MHz spectrum in the Netherlands was set at a third of the estimated value of 800MHz spectrum. The reserve prices for the other bands including 900MHz were then set relative to the 800MHz reserve price with adjustments made for differences between the bands in relation to expected roll-out costs, licence durations, lot sizes and whether the spectrum was paired or unpaired. Reserve prices for bands other than 800MHz in the Dutch multi-band auction should therefore relate to market value.

[23] In first 4G auction in Spain, two lots of 900MHz were available, a 2x5MHz lot and a 2x4.8MHz lot. The 2x4.8MHz lot went unsold in the auction.

existing frequencies and the operators were restricted to bidding for just one lot each, only Vodafone could have acquired spectrum that was contiguous with its existing frequencies. The lack of bids from Optimus and TMN for the remaining 2x5MHz lot suggests that these operators' valuation for incremental, non-contiguous spectrum was below the reserve price of £0.354 (though this does not necessarily form an upper bound on 900MHz market value in general, as the value would have been depressed by the fact that contiguity could not be achieved with existing holdings).

69. There was some unsold spectrum in the 2002 Austrian auction. Specifically, 900MHz spectrum was auctioned alongside 1800MHz in Austria. The same per MHz reserve prices was set for 1800MHz and 900MHz. More than half of the available 2x18.8MHz (2x16.8MHz of 900MHz and 2x2MHz of 1800MHz) spectrum went unsold. Only two existing operators – Mobilkom and T-Mobile participated in the auction, winning 2x7.4MHz of 900MHz between them at reserve prices. There were no reported spectrum caps for this auction, but the operators in Austria may not have been particularly spectrum-hungry in 2002, given their existing holdings.[24] The unsold spectrum from 2002 was subsequently auctioned off in 2004. Reserve prices in the 2004 auction were very low and more bidders took part in this auction. The auction was nonetheless not particularly competitive with all available spectrum allocated at, or just above, reserve. We note that the Austrian regulator has set a relatively high reserve price of approximately £0.24 and £0.30 for 900MHz spectrum in the upcoming multiband auction[25], which would suggest that it does not regard the 2002 auction result as indicative of an upper bound on the market value of spectrum.

70. Overall, looking at auctions where spectrum was allocated at reserve and where reserve prices were set to reflect market value, we consider that lower end of reserve prices in these awards of £0.35 to be a lower bound of 900MHz market value.

71. The 900MHz auction in Norway in 2001 achieved average prices that were slightly above minimum prices (which in this case comprised entirely of the present value of annual licence fees). This auction was a first price sealed bid auction. Four bidders participated in the auction and competed for six 2x1.15MHz lots of E-GSM spectrum. Only three bidders were successful,

[24] Mobilkom and T-mobile had been awarded approximately 2x8MHz of 900MHz spectrum in 1996. Orange had entered the market in 1997 following the award of an 1800MHz licence and a subsequent award of 1800MHz spectrum in 1999 saw the entry of fourth player tele.ring. In 2000, the 3G auction produced six winners of 2.1GHz spectrum whilst later in a 2001 auction, Orange, T-Mobile and Mobilkom acquired further 1800MHz spectrum.

[25] Frequency specific blocks at the edges of the 900MHz bands have a lower reserve price of €23.4m while frequency generic blocks in the rest of the band have a reserve price of €29.9m. Reserve prices were converted to per pop per MHz terms base on an exchange rate of £1 to €1.2 and population figure of 8.2m. See https://www.rtr.at/en/tk/multibandauktion_AF/F1_11_AuctionRules_Web_Multibandauction_2013.pdf for proposed reserve prices.

winning two lots each. Even though there were more bidders than winners, the lowest winning bid was just NOK2,525 (£196) for a lot suggesting that the losing bidder might not have imposed a significant competitive constraint on other bidders. Therefore, we consider that this auction was unlikely to have been very competitive.

72. The Austrian 2008 auction also achieved prices that were slightly above minimum prices. Perhaps because only a small amount of spectrum (2x0.8MHz) was allocated in the 2008 auction, the final price was lower than the reserve price of the earlier 2002 auction, which, as we have explained above, does not provide a good indication of market value.

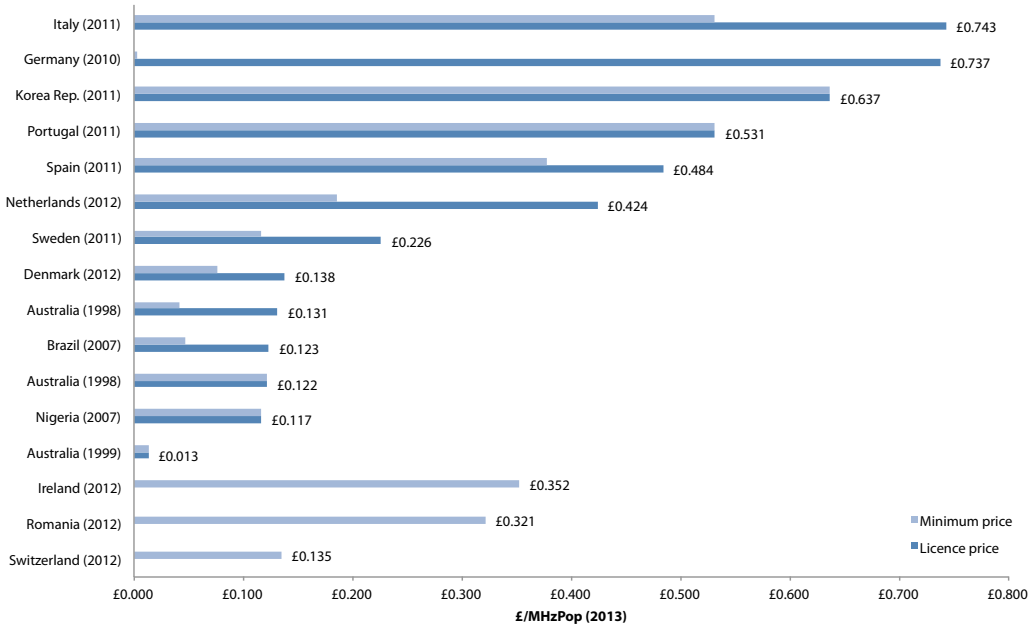
73. There was strong competition for 900MHz in the Hungary and Hong Kong auctions and these auctions achieved significantly higher prices than the rest of the sample. While the Hungarian auction result was later annulled, it provides an indication of the willingness to pay for 900MHz spectrum in Hungary. As half of the available spectrum was reserved for a new entrant, the three existing incumbents were left to compete for a total of 2x5.8MHz, and the high price seems to reflect intense competition. Similarly, the high price in Hong Kong may be seen as reflecting strong competition for spectrum in a densely populated market with five operators serving a population of seven million: six bidders were competing for two available lots of 2x5MHz. However, considering that incumbents in Hong Kong and Hungary were competing for a small amount of spectrum, the Hong Kong and Hungary prices may not be representative of the average value of 900MHz spectrum. They may be regarded as an extreme upper bound estimate of 900MHz value, and it may be more reasonable to use the Greek reserve price as an upper bound. This would suggest an estimate of market value ranging from £0.35-£0.46.

74. As 800MHz and 900MHz have similar propagation characteristics and are generally considered of similar technical merit as discussed in Annex C, we will compare this range to 800MHz prices next.

2.2.2 800MHz

75. Our 800MHz benchmark sample includes all 800MHz auctions in our Spectrum Awards Database, including auctions outside of Europe (where 800MHz spectrum is not part of the digital dividend). Prices achieved in these auctions are shown in the figure below.

Figure 4: 800MHz auctions[26]



76. Average 800MHz auction prices vary quite widely from £0.01 to £0.74, but this range is narrowed to £0.14 to £0.74 when looking only at digital dividend auctions in Europe. The extremely low price achieved in the Australian auction in 1999 reflect that this comprised a single lot of 800MHz spectrum covering the remote central area in Australia that was reserved for new entrants and was won by Hutchison at reserve. There is no indication to suggest that reserve prices for 800MHz in the 1999 Australian auction were set to reflect market value, and therefore we do not consider this figure to be a useful benchmark of market value.

77. Auctions in Nigeria and Australia in 1998 (Second PCS auction) were not competitive and spectrum was awarded at reserve prices. These reserve prices were set at a similar level to the final prices achieved in the first PCS auction in Australia in 1998 and in the Brazilian auction where there was some competition and final prices did exceed reserve. Prices from these benchmarks are lower than that achieved in the European digital dividend auctions.

78. In the Australian auctions 2x20MHz of spectrum was available across 25 regions. 2x10MHz of this available spectrum in urban areas and 2x5MHz in rural areas was reserved for new entrants. There were 6 unsold 800MHz lots in the first PCS auction in 1998, 3 of which were in urban areas and the remainder

[26] We note that in our "Spectrum Value Report 2012" the average licence price paid in Germany was higher than in Italy, this is due to the use of a predicted PPP rate for Italy in the "Spectrum Value Report 2012" (as an official rate for 2011 was unavailable at the time of publication) which differs from the actual PPP rate used in this report (now available) to convert the Italian licence prices.

in rural areas. These unsold lots were auctioned in a subsequent auction later that year. The same spectrum caps limited existing operators Telstra, Optus and Vodafone to acquire 2x10MHz in urban areas and 2x15MHz in rural areas. Five of the unsold lots were allocated in this second auction process. The last remaining unsold lot, which was one of the blocks reserved for a new entrant was subsequently won by Hutchison at reserve in a third PCS auction in 1999 as noted above.

79. In Europe, the highest prices for 800MHz value were achieved in Germany and Italy. In both these auctions, all four existing incumbents competed for six available lots of digital dividend spectrum. In comparison, the countries that saw the lowest 800MHz prices in Europe – Denmark and Sweden – had two existing operators bid jointly in the auction, which would have reduced competition. While both these auctions had significant premiums over reserve (80% and 95% respectively), reserve prices in these auction were significantly lower than in other European countries which makes this premium not a good measure of competitiveness. In addition, Denmark imposed an onerous coverage obligation on licensees to provide a 10 Megabyte per second service (Mbps) to areas currently lacking these speeds (although bidders could bid for exemptions). The cost of discharging this obligation (or bidding for an exemption) would reduce licence value[27]. Therefore we consider that there are good reasons why 800MHz value in the UK should be in excess of final prices from the Swedish and Danish auctions. Indeed we note that the reserve price of 800MHz in the UK auction[28] exceeds the Swedish and Danish benchmarks and that all available 800MHz spectrum was assigned in the UK auction (which used lot-specific reserve prices in establishing the minimum amount that bidders had to pay for spectrum).

80. In the Spanish auction the smallest of the four mobile operators did not participate in the auction and thus there was little competition. While final prices did exceed reserve in Spain, this would seem to be largely down to competition amongst the incumbents to avoid the lowest block in the band, which could have been worth less because of the need to protect adjacent television channels. Premium over reserve for the 800MHz band in Spain was 28%. The lowest 800MHz block in Spain sold at reserve price.

81. In Portugal, there was no excess demand at all for 800MHz and all blocks were awarded at reserve. There is no indication that reserve prices in Portugal were set to reflect market value though we note that the 800MHz reserve price in Portugal was higher than the final auction price in Spain as well as higher than

[27] There may well also have been other licence conditions that may have depressed licence values further. For instance in Denmark we understand that operators must guarantee not to interfere with DTT signals where consumers have decent television equipment at home. This is managed and defined by a pixel model set out by the DBA restricting the transmission power of the operator including certain "no-go" pixels. See http://www.erhvervsstyrelsen.dk/file/251159/information-memorandum-800mhz-auction.pdf

[28] The reserve price of a 2x5MHz lot without coverage obligation was £225m and that of the 2x10MHz lot with coverage obligation was £250m. With a UK population of 63m, this works out to a price per MHz per population of £0.36 and £0.20 respectively.

the 800MHz reserve price in the Irish auction, which was set to reflect the market value of spectrum. Given that all available 800MHz spectrum was allocated in Portugal and Ireland[29], this would suggest that the market value of 800MHz should be in excess of the Irish reserve price at £0.35.

82. In the Netherlands, 800MHz was sold as part of a multi-band award using a CCA format. 2x10MHz was reserved for a new entrant, and ultimately won by Tele 2 (which did not win any other spectrum) having outbid another entrant (ZUMB). The Dutch price in Figure 4 is the price paid by Tele2 for reserved spectrum, and thus reflects the valuation of the losing entrant. The price effectively paid for 800MHz in the Netherlands by incumbent operators cannot be backed out of the package prices. However, we note that the prices that incumbent operators paid for 800MHz should be higher than those paid by the new entrant (£0.42) or the new entrant would have been better off procuring non-reserved spectrum. Therefore we consider that the value of 800MHz spectrum to incumbent operators is likely to be in excess of £0.42.

83. In Romania, Ireland and Switzerland, 800MHz spectrum was awarded in a multiband auction process using a CCA auction format. Reserve prices in these auctions ranged from £0.135 to £0.352 in Ireland. As discussed above, reserve prices in Ireland were set with reference to market value though there is no indication that the same is the case for Romania in Switzerland. In Switzerland, reserve prices were significantly lower than in the rest of Europe and are unlikely to reflect market value. In Romania however, reserve prices are not far off those set in Ireland. We note that in Romania, one 800MHz lot went unsold (though we cannot exclude the possibility that there were bids including the unsold lot that were ultimately unsuccessful given the package nature of the auction).

84. Overall, we consider that the European digital dividend auction benchmarks provide the most reliable indication of the market value of spectrum in the UK. The 800MHz prices achieved in Sweden and Denmark are substantially below those achieved elsewhere, and even lower than the value of the losing entrant in the Netherlands. We believe that these prices – for the reasons explained above – provide a poor indication of the market value of spectrum for the UK. Excluding the Scandinavian auctions would give a range of values from £0.42 to £0.74, which lies inside of the 900MHz benchmark range of £0.35 to £2.72. In particular, the distance between the upper bounds of the 900MHz (£2.72) and 800MHz (£0.74) ranges supports our view that the upper bound of the 900MHz range is an extreme value.

85. 800MHz spectrum has also been allocated by beauty contest in Macau, France and most recently Croatia. In France, a financial bid was part of the evaluation criteria whilst in Croatia and Macau, the regulator had set a fixed price for the

[29] The Irish Auction used package reserve rather than lot-specific reserve prices. However, given that all spectrum sold at prices substantially above reserve, and that the 800MHz band is likely to have been a main source of value, the reserve price set in the Irish auction should provide a good indication of the lower bound.

spectrum.[30] In Macao the fixed price for spectrum set by the regulator was trivial.

86. In France the average financial bid made for spectrum amounted to a price of £0.54, which falls within the range set by 800MHz auction prices. The French licence prices paid by individual operators ranged from £0.42 for blocks at the bottom of the band to £0.66.

87. In Croatia, the fixed licence price was set at £0.75. This is higher than prices achieved in both Italy and Germany, the two auction benchmarks at the top of the range. The weakest of the three operators in Croatia (Tele2) did not apply for a 800MHz licence, leaving 2x10MHz unallocated in Croatia. The Croatian benchmark therefore suggests that a weak incumbent's valuation for 800MHz spectrum is below £0.75.

88. Given that, Italy, Germany and France have comparable economic, demographic and market characteristics to the UK (see Table 2), we expect the value of spectrum in the UK to be comparable to these countries. Further all of these auctions were competitive. The Italian, German and French benchmarks all lie towards the upper end of our benchmark range of £0.42-£0.74.

2.2.3 700MHz

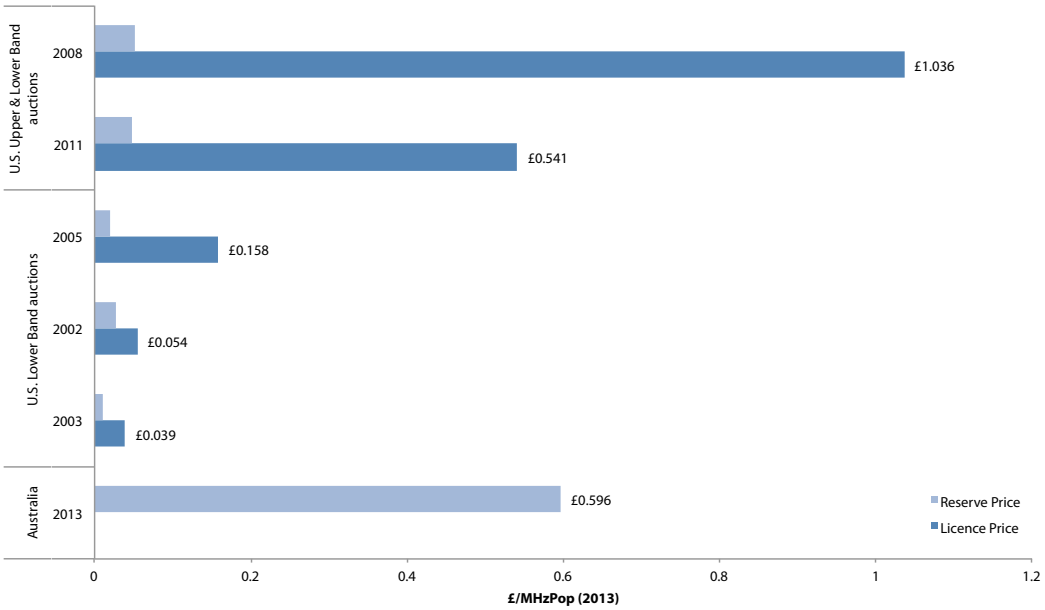
89. Digital dividend spectrum in the US was for frequencies in the 700MHz band. This band has similar propagation characteristics to the 900MHz and 800MHz bands and thus should be similar in value to 800MHz and 900MHz.

90. The digital switchover in the US to free up television spectrum for other uses was carried out in two stages. To support this, the 700MHz band was divided into two sub-bands referred to as the Upper Band (746MHz-806MHz) and the Lower band (698MHz-746MHz). Spectrum in the 700MHz bands has been released in five auctions – three that included only Lower Band spectrum (in 2002, 2003 and 2005) and two that included a mix of Lower Band and Upper Band spectrum (in 2008 and 2011). Figure 5 shows the 700MHz prices achieved in these auctions.[31]

[30] Prices paid in these awards are presented in Section A.1 of Annex A.

[31] Average price calculations did not include the lots of unpaired spectrum which were sold in these auctions.

Figure 5: 700MHz Auctions



91. The prices achieved in these auctions vary substantially. The premium over reserves of these auction increases with time, with the latest auctions in 2008 and 2011 appearing to have been the most competitive. The early auctions for Lower Band spectrum achieved the lowest prices. This may be explained by the fact that spectrum was released under the condition that incumbent broadcasters were allowed to continue to operate in the Lower 700MHz Band until the end of the transition period (2011). Depending on the specific licence, the need to protect incumbent broadcasters could significantly limit what the buyer of the licence could do. In addition to the existing analogue broadcasters, there were a large number of digital broadcasters who were temporarily operating in the Lower band during the transition period. Therefore, the Lower Band auctions between 2003 and 2005 do not provide useful indications of the value of unencumbered 900MHz spectrum.

92. Spectrum in the Upper Band on the other hand was released exclusively for mobile services. Also, by the time of the 2008 auction, there was greater clarity over the timing of broadcasters vacating the Lower Band. The auctions of 2008 and 2011 therefore provide a better indication of the market value of sub-1GHz spectrum.

93. Australia auctioned off 700MHz and 2.5GHz spectrum in a multi-band CCA auction in 2013. The reserve price for 700MHz spectrum was set by the government at £0.59, with the stated aim of obtaining a fair price for industry and making a reasonable return on a valuable public.[32] This reserve price level

[32] See http://www.minister.dbcde.gov.au/media/media_releases/2012/204

has been criticised publicly for being too high. Vodafone has abstained from taking part in the auction and cited the high reserve price as the main deterrent to bidding for 700MHz.[33]

94. When it was apparent that Vodafone would not bid for 700MHz spectrum the government changed the rules to allow qualified bidders to bid for up to 2x25MHz of 700MHz spectrum.[34] Despite this rule change and there being three qualified bidders, 700MHz spectrum was allocated close to reserve prices with 2x15MHz of the 2x45MHz available going unsold, suggesting that the value of 700MHz spectrum to the weakest incumbent in a three-player market is below £0.59. This is consistent with the result of the Croatian 800MHz tender, which suggests that the value to the weakest incumbent in a three-player market is below £0.75. At the same time, we note that the market clearing prices for 800MHz spectrum in Italy and Germany were in excess of £0.59. The fact that bidders were allowed to bid for up to 2x25MHz but did not might therefore suggest that the marginal value of spectrum to stronger incumbents over and above holdings of 2x10MHz and 2x20MHz is below £0.59.

95. Overall, these 700MHz benchmarks suggest a sub-1GHz market value of between £0.54 and £1.03, though in a three-player market with a weak third player, the market value of spectrum could be below this range. This range overlaps to some degree with our 800MHz benchmark range, but is generally higher. This may simply reflect higher intrinsic spectrum values for the lower frequencies, though modelling work by Kerans et al. suggests that this effect may not be material.[35] US operators could also have higher value for spectrum relative to European ones because of the higher ARPU and the lower mobile penetration, which provides greater untapped potential, although this effect may not be as strong as one might expect because the higher ARPU and lower penetration in the US compared with Europe may simply be the result of the much greater prevalence of multiple SIM cards in Europe.

2.2.4 1800MHz

96. In considering 1800MHz market value, we use a sample that includes 1900MHz licences auctioned in the US and Canada, which are being used for comparable services. We also include in our sample an auction in Mexico where 1800MHz spectrum was paired with 1900MHz spectrum.[36] We nevertheless refer these bands as "1800MHz" in our discussion.

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[33] See http://www.zdnet.com/au/vodafone-pulls-out-of-pricey-4g-spectrum-auction-7000008852/

[34] The spectrum cap for 700MHz was previous 2x20MHz. See http://www.computerworld.com.au/article/444624/conroy_sets_digital_dividend_auction_price_ups_spectrum_limits/

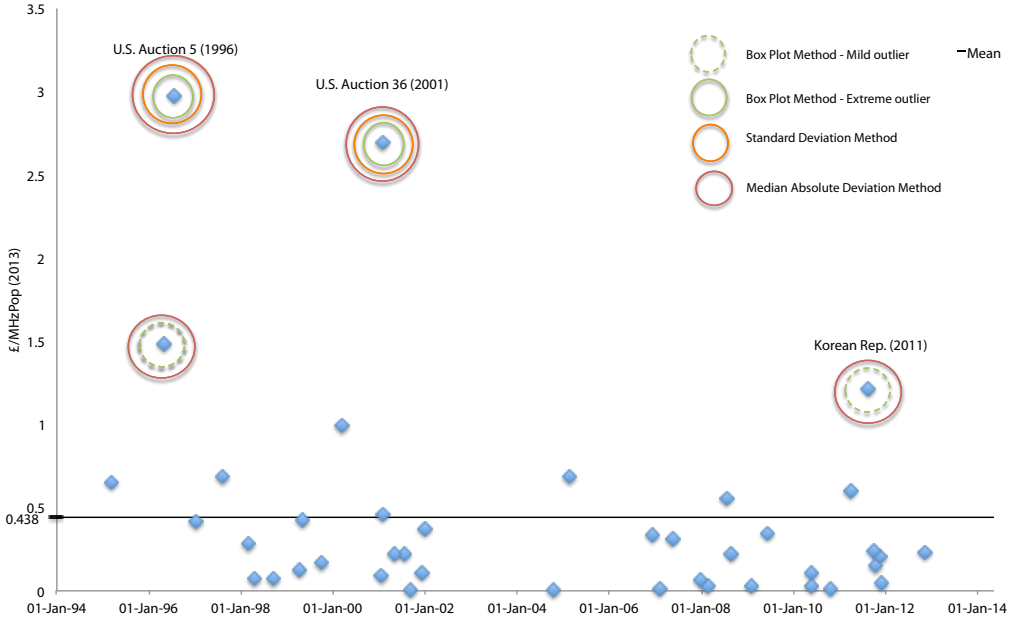
[35] Kerans et al. (2011) suggest that for frequencies below 850MHz non-frequency related limitations of network technology dominate and there are therefore no further value gains from the better propagation characteristics of lower frequencies. See Kerans, A, Vo, D., Conder, P., Krusevac, S. (2011), *Pricing of Spectrum Based on Physical Criteria*, Proceedings of IEEE DySPAN (2011), pp. 223–230.

[36] The downlink was in the 1800MHz band while the uplink was in the 1900MHz band.

97. There are significantly more data points for the 1800MHz band than in the sub-1GHz bands. Figure 6 below presents a scatter diagram of average 1800MHz prices from auctions since 1994. Outliers identified by the three methods discussed in Section 2.1.3 are circled.

98. Again, there is a large variation in prices in our sample. Prices from 2003 onwards are however more similar.[37] The average price of 1800MHz spectrum for the period from 1994 to 2013 is £0.44. The lowest price points are generally obtained for spectrum that sold at reserve. The highest price points come from two auctions in the US in 1996 and 2001 where prices were £2.97 and £2.69, respectively. Both these auctions are identified as being outliers by all three methods. Two other data points – US Auction 5 in 1996 and the Korean auction in 2011 are identified as being outliers by the Box Plot Method and Median Absolute Deviation Method. Therefore, we will exclude the US auctions in 1996 and 2001 deemed to be outliers by all three methods from the 1800MHz sample.

Figure 6: 1800MHz Auctions



99. In Table 3 we present summary statistics for the sample of all 1800MHz auctions excluding the US 1996 and 2001 auctions as outliers ("1995-2012, excluding outliers") and for a sub-sample excluding all uncompetitive auctions where spectrum sold at reserve price ("1995-2012 excluding outliers, above reserve").

[37] The sample between 1995-2002 has an average price of £0.67 and a standard deviation of 0.835 while the sample between 2003-2012 has an average price of 0.262 and a standard deviation of 0.269.

Table 3: 1800MHz Sample Summary Statistics

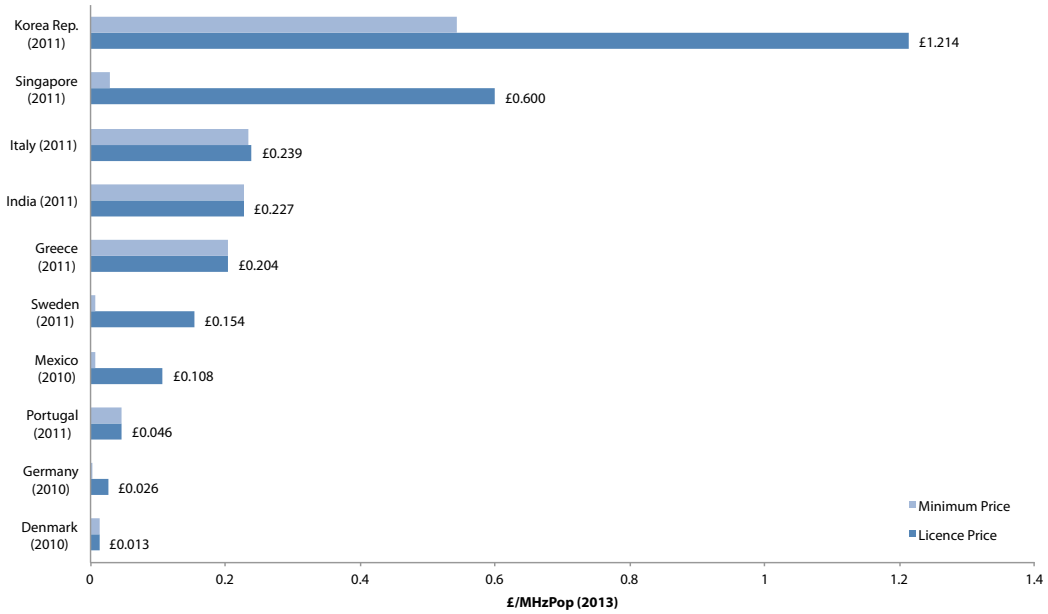
Sample	Observations	Mean	Standard Deviation	95% confidence interval
1995-2012 excluding outliers	39	0.316	0.339	0.209 – 0.422
1995-2012 excluding outliers, above reserve	29	0.373	0.361	0.242 – 0.505

100. The average price of 1800MHz in the sample all auctions except the two extreme outliers is £0.32. Excluding auctions where spectrum sold at reserve increases the mean as well as the sample variance.

101. Excluding auctions where spectrum sold at reserve would exclude observations where reserve prices have been set at a relatively high level (perhaps in anticipation of weak competition). Retaining these observations also ensures consistency with our treatment of the sub-1GHz bands. Overall, we consider that the range of £0.21 to £0.42 provides a suitable benchmark for 1800MHz market value.

102. In the remainder of this section, we discuss a number of individual auction results in more detail. In Figure 7 to Figure 10 we present the individual prices of all auctions in the period 1995-2012. For ease of presentation we have divided the sample of auctions between 1995-2012 into four time periods.

Figure 7: 1800MHz Auctions 2010-2012



103. 1800MHz auction prices between 2010 to 2012 ranges from £0.013 in Denmark to £1.214 in Korea. There were a few uncompetitive auctions where spectrum was allocated at reserve prices, which have been set around the lower bound of our £0.21-£0.42 range. In Germany, Sweden and Mexico final prices exceeded reserve, but reserve prices were very low in these countries. With

final prices lying below reserve prices set for example in Italy and Greece, these prices may not provide a fair indication of market value.

104. In Sweden, 3 bidders competed for 2x35MHz of 1800MHz spectrum. This spectrum was made available for auction after PTS renewed 1800MHz licences in 2010, deciding to renew spectrum in part of the band and auction off the remaining 2x35MHz. There was no spectrum cap in this auction. However, two of the existing operators bid jointly, which would have reduced the level of competition in the auction. The spectrum was eventually won by those operators who had existing holdings in the 1800MHz band, and with reduced competition the Swedish result may not be a reliable indicator of market value.

105. Final 1800MHz prices in Germany were quite low – indeed, even lower than reserve prices in Portugal. This suggests that there was little competition for 1800MHz in Germany, driven by the fact that the existing frequency holdings in the band split the available blocks in such a manner that there were obvious contenders for the available spectrum, and there was no new entry. Given the low level of competition in this band, it is unlikely that this benchmark reflects full market value.

106. In Portugal there were three unsold 2x5MHz lots in the 1800MHz band, with a total of 2x57MHz of 1800MHz having been available in this auction. There was a 1800MHz spectrum cap of 2x20MHz including operators' existing holdings (operators held 2x6MHz each) which restricted the three bidders to bid for a maximum of 2x14MHz in the auction. The three existing operators bought the maximum amount of spectrum allowed and the remaining spectrum in the band went unsold. Further we note that, there is no indication to suggest that reserve prices had been set to reflect market value.

107. There has been plenty of commentary on the high reserve prices set by the TRAI in India[38], which were at a similar level to reserve prices in Greece and Italy. We note that the 1800MHz reserve price in India was set to reflect *"the perceived value of spectrum to the user"*[39]. Value of spectrum to the user was estimated as a mark up over the 2.1GHz prices achieved in the Indian 3G auction in 2010[40]. This reserve price level was subsequently reduced by just under 30% of that proposed by TRAI following a review and under recommendations of the Empowered Group of Ministers.[41]

108. Despite the reduction in reserve prices, competition in the Indian 1800MHz auction was very weak with over half of the available lots not allocated. However, it is not clear whether this was the impact of high reserve prices, or

[38] See for instance: http://articles.timesofindia.indiatimes.com/2012-11-16/india-business/35156441_1_reserve-price-telecom-spectrum-price-of-2g-spectrum

[39] Page 42 of TRAI, *Recommendations on Auction of Spectrum (w.r.t. reference received from DoT on recommendations of 23rd April 2012)*, 12 May 2012.

[40] See pages 91-101 of TRAI, *Recommendations on Auction of Spectrum*, 23 April 2012.

[41] See http://www.medianama.com/2012/08/223-india-sets-spectrum-auction-reserve-price-at-2-5-bn-for-gsm-3-2-bn-for-cdma-timeline/

the effect of the appetite for spectrum in India having been weakened by the damage to confidence in the regulatory environment in India. 1800MHz licences controversially awarded in 2008 were annulled by a Supreme Court decision in 2012, and operators were thus in a position of having to 'buy back' frequencies in the 1800MHz band they thought they had already obtained. A number of operators exited the market without even taking part in the auction.[42] Further the TRAI imposed a substantial tax on operators with spectrum holdings exceeding 2x4.4MHz,[43] which could have discouraged bidding for 1800MHz in the auction.

109. The two auctions during this period that yielded the highest prices were held in Singapore and Korea. Both awards produced prices far above the upper bound of our range. In the Singapore auction in 2011, only a single block of 2x5MHz was auctioned, and thus the Singapore price may provide a poor indication of the market value of 1800MHz spectrum in general.

110. In the Korean auction, spectrum in three bands was auctioned – 2x5MHz in the 800MHz band, and 2x10MHz in each of the 1800MHz and 2.1GHz bands. Spectrum in the 2.1GHz band was reserved for a new entrant. Competition between two incumbents (SK Telecom and KT Corp) was thus limited to two bands. Competition was intense in the 1800MHz band whilst the 800MHz spectrum was awarded at reserve price. The attractiveness of 1800MHz over 800MHz in Korea may be due to wider deployment of LTE in the 1800MHz band across the Asia Pacific in combination with the small amount of 800MHz spectrum available. Prior to the auction, SK Telecom held 2x15MHz of 800MHz and 2x30MHz of 2.1GHz, but no 1800MHz spectrum.[44] SK Telecom's high valuation for 1800MHz spectrum could therefore be tied to high potential revenues from LTE in Korea. We note that it has been reported that SK Telecom has manage to increase its ARPU since rolling out LTE.[45]

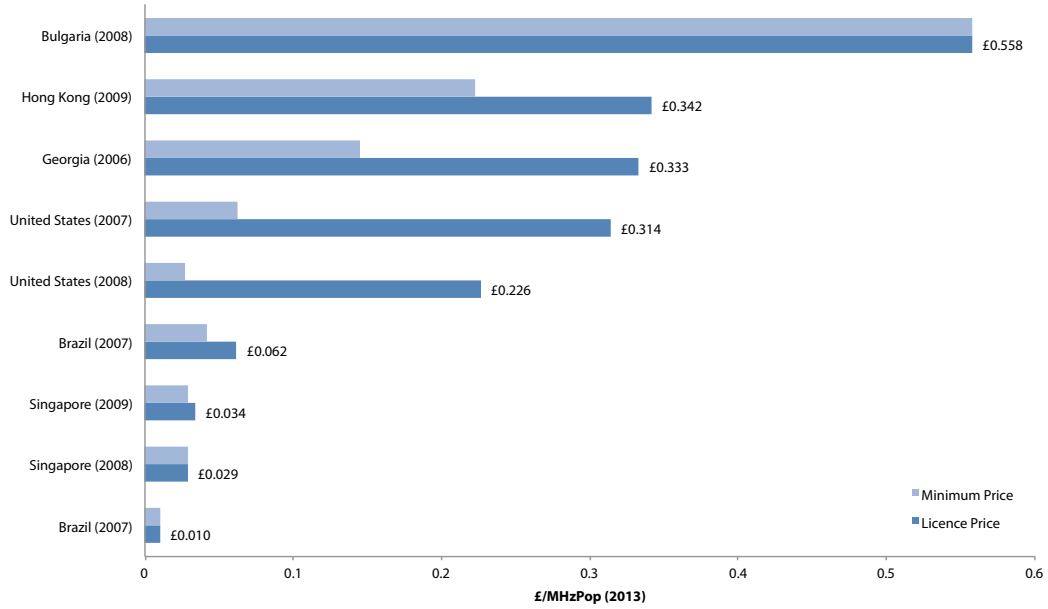
[42] Batelco and Etisalat exited the Indian market following the Supreme Court Order.

[43] See http://articles.timesofindia.indiatimes.com/2012-10-09/india/34342375_1_excess-spectrum-mhz-of-airwaves-frequencies-spectrum-allocation

[44] See http://www.dailywireless.org/2011/08/29/south-korea-auction-its-done/

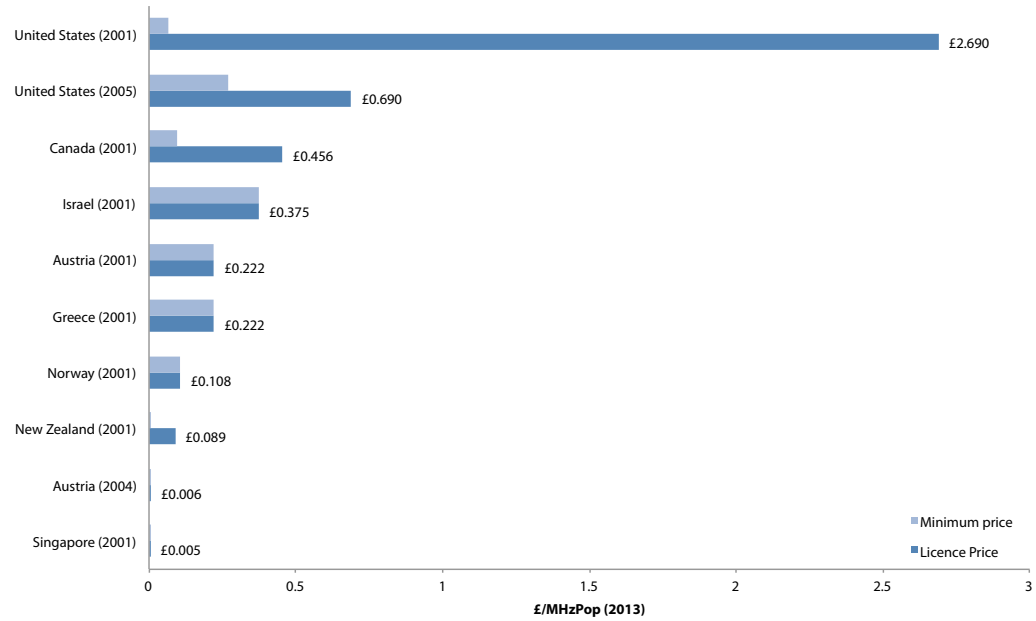
[45] See http://english.hankyung.com/news/apps/news.view?c1=06&nkey=201208031828261

Figure 8: 1800MHz Auctions 2006-2009



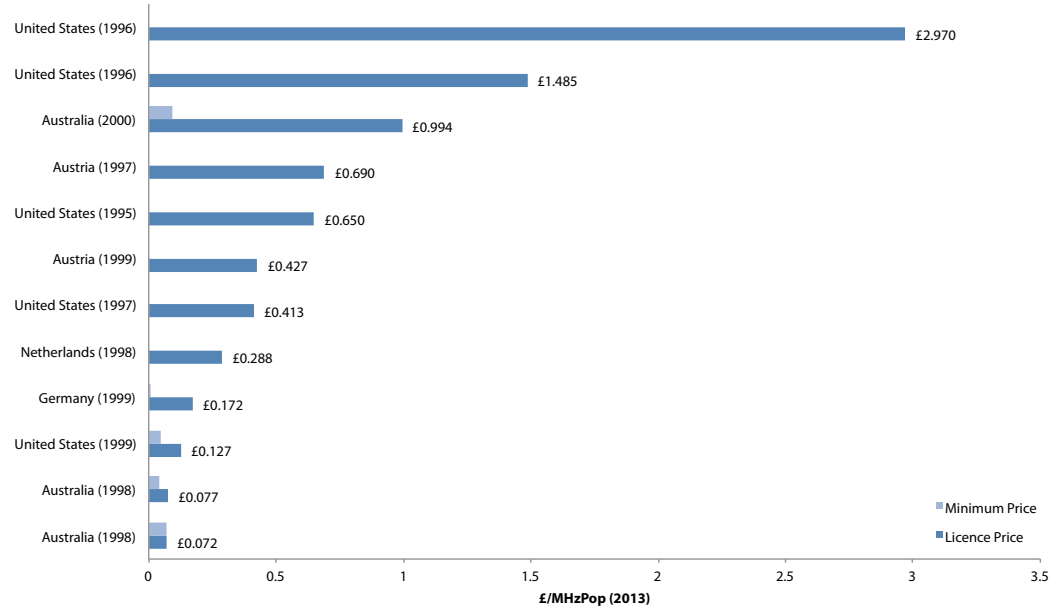
111. A number of auctions in the period 2006 to 2009 have been competitive with final prices exceeding reserve. One exception is Bulgaria, where only one lot of 2x5MHz was available and the reserve price was set very high (and indeed above the top end of our range). The auctions that took place in Brazil and Singapore had relatively low reserve prices and saw little or no competition (small or no premium over reserve despite relatively low reserve prices). These auctions produced prices substantially below the lower bound of our range. In the first of the Brazilian auctions where spectrum was awarded at reserve, spectrum was offered in the form of regional licences with only the Greater Sao Paulo licence allocated and the rest of the licences going unsold. These licences however were awarded in an auction later that year at prices slightly exceeding reserve. The remaining auction results in this period less Bulgaria fall within our range.

Figure 9: 1800MHz Auctions 2001-2005



112. In the period 2005 to 2001, there were a number of uncompetitive auctions that allocated spectrum at reserve prices (where the premium over reserve is small). In the Austrian auction in 2001, there was one unsold lot of 2x2MHz that was subsequently allocated in the 2004 auction where significantly lower reserve prices were used. Of the competitive auctions, prices exceed the upper bound of our estimated value range of £0.21 to £0.42, though not by a huge margin. The Canadian auction took place around the time of the telecoms bubble, which may have inflated bids.

Figure 10: 1800MHz Auctions 1995-2000



113. The period between 1995-2000 shows the highest 1800MHz prices in our sample. We note that in this period it was common for regulators to set low or no reserve prices.

114. Less competitive auctions where final prices were around or just above reserve prices (Australia in 1998 and US in 1997) fall below our estimated value range. There is no indication that reserve prices in these auctions have been set with reference to market value. The German 1800MHz auction followed an SMRA format with discretionary bidding. It is generally considered to be a prime example of how bidders may use discretionary bidding to coordinate their behaviour and limit competition.[46] The prices achieved in the Netherlands, the US (1997) and Austria (1999) fall within (or in the case of Austria, barely above) our range, but the remaining auction prices are above the upper bound.

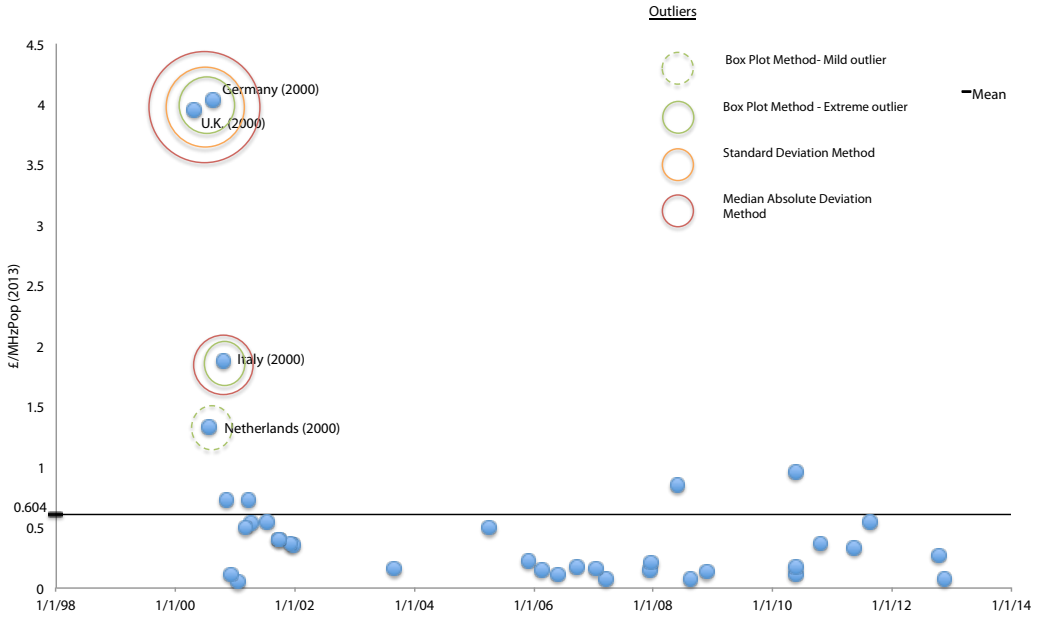
115. Looking at individual observations suggests that in most cases prices achieved for 1800MHz spectrum in competitive auctions lie within or above our benchmark range this range. This is true for a wide range of countries with varying economic and market conditions. Prices achieved in the most suitable comparator countries (Germany and Italy) are at the lower end, or below the lower bound of the range, which is however explained by the fact that these awards were not competitive and reserve prices in Germany were set at a low level.

[46] V Grimm, F Riedel and E Wolfstetter, 2003, *Low Price Equilibrium in Multi-Unit Auctions: The GSM Spectrum Auction in Germany*, International Journal of Industrial Organization, Vol. 21, ppp. 1557-1569.

2.2.5 2.1GHz

116. There are 36 observations in total in our sample of 3G auctions. Even though it is covering a shorter time period, the sample produces an even wider range of prices than the 1800MHz sample[47] with an average price of £0.60. This is because the sample includes a number of observations from the period of the telecoms bubble that have produced extremely high prices. These auctions are clearly flagged up as outliers by the three methods discussed above. All three methods identify the UK and German 3G auctions as outliers; the Italian 3G auction is identified as an outlier by the Box Plot Method and Median Absolute Deviation Method, and the Dutch 3G auction is a mild outlier according to the Box Plot Method. For the purpose of our analysis we will exclude the German and UK 3G auctions.

Figure 11: 2.1GHz Auctions and Awards



117. In Table 4 we present summary statistics for the sample of all 2.1GHz auctions excluding the German and UK 3G auctions as outliers ("2000-2012, excluding outliers") and for a sub-sample excluding all uncompetitive auctions where spectrum sold at reserve price ("2000-2012 excluding outliers, above reserve").

[47] The standard deviation of our 1800MHz sample is 0.6 and that of our 2.1GHz sample is 0.9.

Table 4: 2.1GHz Sample Summary Statistics

Sample	No. Of Observations	Mean	Standard Deviation	95% Confidence interval
2000-2012 excluding outliers	34	0.405	0.391	0.273 – 0.536
2000-2012 excluding outliers, above reserve	26	0.420	0.437	0.252 - 0.588

118. The average price of 2.1GHz spectrum achieved in auctions from 2000 to 2012 excluding the two outliers is £0.41. Excluding all auctions that sold at reserve from this sample leads to a higher mean of £0.42, and also a larger variance.

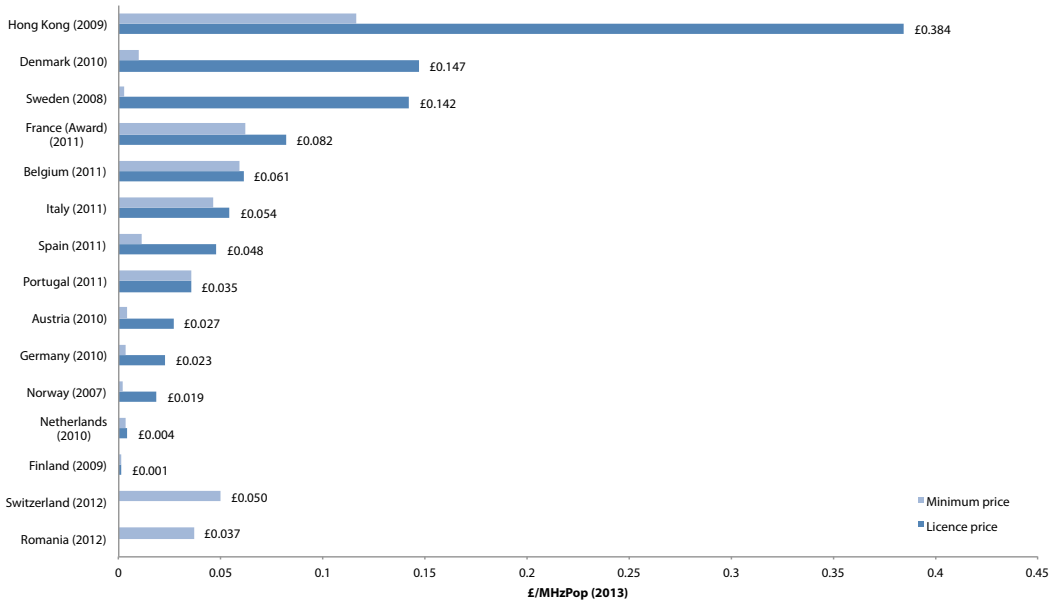
119. Consistent with our approach in the case of 1800MHz, we suggest estimates of market value for 2.1GHz based on the sample all auction excluding outliers of UK and German 3G auctions, producing a range of £0.27 to £0.54.

2.2.6 Paired 2.6GHz

120. With the exception of France, where a hybrid award process was used, spectrum in the 2.6GHz band has almost exclusively been awarded by auction. Prices achieved in 2.6GHz awards are presented in Figure 12 below.

121. 2.6GHz spectrum was awarded in Switzerland and Romania via a multiband CCA in 2012. The price of 2.6GHz spectrum in these auctions cannot be separated from the package prices paid by winners, and we include the reserve prices set in these auctions, though we note there is no indication that reserve prices in either Switzerland or Romania were set relative to market value.

Figure 12: 2.6GHz Auctions and Awards



122. 2.6GHz prices vary widely, ranging from £0.001 to £0.38. Many auctions saw low levels of competition and thus prices being determined by the reserve price. The Netherlands and Finland had trivial reserve prices and very little competition, and the outcomes of these awards are therefore likely significantly to underestimate market value.

123. In the Austrian, Norwegian and German auctions, prices ranged from £0.02 to £0.03 – substantially below the reserve prices set in the majority of 2.6GHz auctions. Even though these auctions produced prices above their respective reserve price levels, competition may have been weak. In our Spectrum Value Report, we have discussed that in the German multiband auction, demand for 2.6GHz spectrum may have been driven by bidders trying to 'park' eligibility rather than genuine demand for incremental spectrum. This would imply that despite prices exceeding reserve there was little competition for these frequencies. Prices in Austria exceeded reserve by a sizeable margin, but reserve prices were extremely low (as required by law) and with four bidders and four winners competition may not have been overly strong. Norway was the first country to auction spectrum in this band in Europe and thus bidders may have faced a high level of uncertainty of their valuations of 2.6GHz spectrum. Given these factors these auctions might not give a good indication of market value.

124. In Australia, Vodafone did not participate in the 4G multi-band auction and there were only three bidders. There was little competition in the auction and any excess demand for the 2.5GHz frequencies was resolved within three rounds of bidding. Optus and Telstra both won 700MHz as well as 2.5GHz spectrum, and it is therefore not possible to determine the amount they paid for 2.5GHs spectrum. TPG Internet won only 2x10MHz of 2.5GHz spectrum,

and the Australian benchmark in Figure 12 above is TPG Internet's package price. TPG Internet won its package at reserve price.

125. Unlike the 700MHz spectrum, where the reserve prices was set by the government, the government had instructed ACMA to set the reserve price for the 2.5GHz band, and there is no indication that the £0.013 set by ACMA reflects market value. Indeed, we note that this reserve price is lower than most other benchmarks in this sample, including both the competitive and less competitive auctions in Europe. Therefore, we do not consider the Australian benchmark to be a useful indication of market value.

126. The highest price for 2.6GHz spectrum was £0.38, paid in the 2009 Hong Kong auction. This price is substantially higher than prices achieved in other auctions and may not provide a good indication of spectrum value in the UK, given the very different economic, demographic and mobile market conditions.

127. Excluding the Hong Kong award and uncompetitive auctions suggests a value of 2.6GHz spectrum in the range of £0.05-£0.15. It should be noted however, that except for Sweden and Denmark (the latter of which sets the upper bound) none of the auctions in this range were particularly competitive and thus the lower bound should be considered a conservative estimate.[48]

128. This range is also consistent with the price paid in an award of 2.6GHz spectrum in France (£0.08) where spectrum was allocated in a hybrid auction-beauty contest. Bidders were assessed on a financial bid and their willingness to host mobile virtual network operators obligation.

2.2.7 Summary of band specific auction benchmarks

129. Our estimated value range for sub-1GHz, 1800MHz, 2.1GHz and 2.6GHz are summarised in Table 5 below.

Table 5: Benchmark values

Band	Value range
800MHz	£0.42 - £0.74
900MHz	£0.35 - £0.46
1800MHz	£0.21 - £0.42
2.1GHz	£0.27 - £0.54
2.6GHz	£0.05 - £0.15

[48] See Section 3.5 of Spectrum Value Report 2012.

130. The 900MHz range (£0.35 - £0.46) presents a lower bound estimate of market value for 900MHz, given that it is determined entirely with reference to reserve prices. Assuming that frequencies in the 800MHz and 900MHz bands are of comparable overall value (given their similar technical merits), the 800MHz range suggest that this is indeed the case, and 900MHz spectrum may be worth up to £0.74.

131. Our band-specific benchmarks suggest that sub-1GHz spectrum is worth between 1.7 and 1.8 times as much as 1800MHz spectrum.

132. The benchmark value ranges for 1800MHz and 2.1GHz overlap to a large extent, with the 2.1GHz range being slightly above the 1800MHz range. This is broadly in line with the evidence from technical and business modelling, which suggests that 1800MHz and 2.1GHz spectrum should be of comparable value. However, whilst some technical models reviewed in Annex C suggest that 1800MHz has slightly superior propagation characteristics compared with 2.1GHz spectrum, our auction benchmarks suggest that this difference may be outweighed by the impact of other value drivers that affect the commercial value of spectrum (e.g. the standards governing the use of the respective bands).

133. At the upper end of the 1800MHz and 2.6GHz range, 1800MHz spectrum is worth three times as much as 2.6GHz spectrum. This is consistent with that suggested by technical and business modelling (see Annex C).

2.3 CCA cross checks

134. Although the package prices paid in multi-band CCAs do not allow us to calculate prices for spectrum in the individual bands, we can use information from these awards as a cross check of our band-specific value estimates. In this section, we calculate the implied value of a package using our benchmark ranges and compare them to actual package prices paid (calculated as upfront payments plus discounted fees). Both implied package prices as well as actual package prices are expressed in 2013 GBP terms.

135. In some these CCAs, spectrum licences with different licence durations are offered. A package won may in turn contain spectrum licenced for different durations. In order to calculate the implied package prices, we adjust our benchmark values in Table 5 above for differences in licence durations so that the adjusted benchmark values match the durations of the licences concerned. This is done using the same methodology described in Section 2.1.1 and listed in Figure 1. The implied package value is then calculated by multiplying the adjusted benchmark values with the spectrum endowment of each band in the package and summing over all bands in the package.

136. The Swiss, Dutch and UK auctions included spectrum bands for which we have not calculated price benchmarks (e.g. unpaired 1900MHz and unpaired 2.6GHz spectrum). In cases where winning packages contain spectrum in these bands, we have valued these frequencies at reserve prices when calculating implied package prices. We note however that this method may understate the package prices implied by our benchmark ranges, in particular where reserve prices were relatively low and the packages include a substantial portion of spectrum for which we do not have benchmark values.

137. Overall we find that in the most competitive auctions (Ireland and the Netherlands) prices paid are close to, or above those implied by the upper ends of our value range estimates. Prices in the UK auction mostly lie towards the lower end.

Switzerland

138. In the Swiss multiband auction spectrum in all of the bands covered in our benchmark analysis and unpaired 2.6GHz spectrum was awarded. There were three bidders, all of whom won sizeable packages. Table 6 provides an overview of the outcome, listing the packages won by the three bidders.

Table 6: Package prices in the Swiss auction

	Orange	Sunrise	Swisscom
800MHz (16 years)	20	20	20
900MHz (15 years)	10	30	30
1800MHz (15.4 years[49])	50	40	60
2.1GHz (13.5 years[50])	40	20	60
2.6GHz (18 years)	40	50	40
2.6GHz TDD (18 years)	-	-	45
Auction package price (£millions)	71	222	166
Package price implied by lower bound estimates (£millions)	248	250	365
Package price implied by upper bound estimates (£millions)	480	454	664
Premium over reserve price (%)	0.3	157	43

139. Package prices paid were lower than those implied by the lower bound of our value estimates. However, Sunrise paid a significant premium over reserve for its package when compared with Orange (which practically acquired its spectrum at reserve) and Swisscom. Sunrise's price is relatively close to package price implied by our lower bound estimates. The asymmetry in premiums over reserve between Sunrise and Swisscom suggests that Sunrise did not impose as much of an opportunity cost on Swisscom as Swisscom did

[49] Lots in the 1800MHz band were offered in varying durations. There was one 2x10MHz lot with a licence duration of 18-years and thirteen 2x5MHz lots with a licence duration of 15 years. The weighted average (weighted by MHz) of licence duration across these lots is 15.4 years.

[50] Lots in the 2.1GHz band were offered in varying durations. There were three 2x5MHz lots with a licence duration of 18-years and nine 2x5MHz lots with a licence duration of 12 years. The weighted average (weighted by MHz) of licence duration across these lots is 13.5 years.

on Sunrise, while both imposed an opportunity cost on Orange. This suggests that competition overall was not very strong and somewhat asymmetric.

Romania

140. Licences on offer in the Romanian multiband auction were for two time periods, and winning packages contained a mixture of spectrum licenced for 1.25 years, and for 15 years in varying quantities.

141. In the Romanian auction all spectrum was sold very close to, or at the reserve price. Winning packages and package prices are presented in the table below. As reserve prices were set towards the lower end or below our estimated value ranges, package prices are therefore either around or below the lower bound of package values implied by our estimates.

142. In the Romanian auction a fifth bidder – 2K Telecom won 30MHz of unpaired 2.6GHz spectrum. Since we have not benchmarked the unpaired 2.6GHz band, in Table 7 below, we will not compare 2K Telecom's actual package price against implied packages prices from our benchmarks.

Table 7: Package prices in the Romanian auction

	Cosmote	Orange	Vodafone	RCS&RDS
800MHz (15 years)	10	20	20	-
900MHz (1.25 years)	0	25	25	0
900MHz (15 years)	20	20	20	10
1800MHz (1.25 years)	0	30	30	0
1800MHz (15 years)	50	40	60	-
2.6GHz (15 years)	20	40	-	-
2.6GHz TDD (15 years)	-	-	15	-
Auction package price (£millions)	311	392	395	69
Package price implied by lower bound estimates (£millions)	427	525	572	66
Package price implied by upper bound estimates (£millions)	764	944	995	87
Premium over reserve price (%)	4	5	2	0

Ireland

143. The Irish multiband auction included 800MHz, 900MHz and 1800MHz spectrum. Licences for two time periods were offered. Winning packages therefore contained a mixture of spectrum that is licenced for 2.4 years, and for 15 years, in varying quantities.

Table 8: Package prices in the Irish auction

	H3G	Meteor	Telefonica	Vodafone
800MHz (2.4 years)	0	20	20	20
800MHz (15 years)	0	20	20	20
900MHz (2.4 years)	10	10	20	20
900MHz (15 years)	10	20	20	20
1800MHz (2.4 years)	20	20	0	30
1800MHz (15 years)	40	30	30	50
Auction package price (£millions)	67	166	150	190
Package price implied by lower bound estimates (£millions)	54	99	99	121
Package price implied by upper bound estimates (£millions)	96	168	165	209
Premium over reserve price (%)	71	160	125	138

144. Package prices paid by all four bidders lie within the range implied by the lower and upper bounds of our estimates. The premium paid by H3G over the reserve price of its package is somewhat lower than the premiums paid by other winners, suggesting again that competition for incremental spectrum was asymmetric and that H3G imposed a lower opportunity cost on other winners than vice versa.

The Netherlands

145. The Dutch multiband auction offered 41 licences in the 800MHz, 900MHz, 1800MHz, unpaired 1900MHz, 2.1GHz and unpaired 2.6GHz bands. Licences in the 800MHz, 900MHz, 1800MHz and unpaired 2.6GHz licences had a duration of 17 years while the unpaired 1900MHz and 2.1GHz frequencies had a licence term of 4 years.

146. 2x10MHz in the 800MHz band was reserved for a new entrant though no spectrum caps were imposed on any bidder. There was thus great scope for competition amongst the existing incumbents. The auction ran for a month and a half, from the end of October to mid-December 2012. The table below summarises the packages won by each licensee.

Table 9: Package prices in the Dutch auction

	KPN	T-Mobile	Vodafone	Tele2
800MHz (17 years)	20	0	20	20
900MHz (17 years)	20	30	20	0
1800MHz (17 years)	40	60	40	0
1900MHz TDD (4 years)	0	14.6	0	0
2.1GHz (4 years)	10	0	10	0
2.6GHz TDD 17 years)	30	25	0	0
Auction package price (£millions)	1,116	753	1,139	133
Package price implied by lower bound estimates (£millions)	394	367	389	133
Package price implied by upper bound estimates (£millions)	677	617	672	232
Premium over reserve price (%)	810	692	852	130

147. The three existing incumbents – KPN, Vodafone and T-Mobile all paid a package price that is higher than the price implied by our upper bound estimates.

The UK

148. 800MHz and paired and unpaired 2.6GHz spectrum were sold in the UK multiband auction. There were seven participating bidders in the auction and five winners.

Table 10: Packages prices in the UK auction

	EE	H3G	O2	Vodafone	Niche
800MHz (20 years)	10	10	20	20	0
2.6GHz (20 years)	70	0	0	40	30
2.6GHz TDD (20 years)	0	0	0	25	20
Auction package price (£millions)	619	255	610	863	202
Package price implied by lower bound estimates (£millions)	485	265	530	656	95
Package price implied by upper bound estimates (£millions)	1,129	467	933	1,312	284
Premium over reserve price (%)	78	0	120	159	344

Note: prices include the payment to DMSL to fund the costs of mitigating DTT co-existence of £30m per 2x5MHz block in the 800MHz band

149. The package prices of Vodafone, EE, O2 and Niche fall roughly within the lower half of derive estimated value range. H3G however paid prices just below those implied by our lower bound estimates. H3G obtained one of its opt in packages at reserve having been the only opt-in bidder.[51]

Australia 4G

150. 2x45MHz of 700MHz and 2x70MHz of 2.5GHz spectrum was available in the Australian 4G auction. All spectrum in the 2.5GHz band was allocated while as mentioned above, 2x15MHz of 700MHz spectrum was unallocated. There were four qualified bidders but Vodafone did not make any bids in the auction hence only three bidders competed for spectrum in the auction. There was little competition within the auction and the bidders won their packages at or just above reserve prices. The package price paid by Telstra and Optus are above our lower bound estimates, mainly due to the high 700MHz reserve prices in the auction. On the other hand, the more moderate 2.5GHz reserve price is below our lower bound estimate of 2.6GHz value. TPG Internet won its package of 2.5GHz spectrum at reserve, hence its package price is below our benchmark range.

[51] See http://www.ofcom.org.uk/static/spectrum/notices-issued-applicants-bidders.pdf

Table 11: Packages prices in the Australian auction

	Optus Mobile	Telstra	TPG Internet
700MHz (15 years)	20	40	0
2.6GHz (15 years)	40	80	20
Auction package price (£millions)	259	518	5
Package price implied by lower bound estimates (£millions)	204	408	20
Package price implied by upper bound estimates (£millions)	408	816	59
Premium over reserve price (%)	0	0.3	0

2.4 Relative band value

151. In this sub-section we provide additional information on the relative prices for different frequency bands in multiband auctions or in separate auctions within the same country. In order to make this exercise meaningful, we limit our attention to awards in which the prices for both of the bands in question exceed the lower bound of our propose valuation ranges summarised in Table 5 above. While such an approach would limit the amount of information on relative band value we do extract from our sample of spectrum auctions, it will ensure that the benchmarks we derive reflect market values of the frequency bands concerned.

152. In cases where final prices are at, or close to reserve, relative band values would largely be determined by relative reserve prices of different bands. While market value reflecting reserve prices in these cases could potentially provide some indication to relative band values, this may not accurately reflect relative market values where regulators have different reserve price objectives for different bands of spectrum. Australia is a clear case in point.

153. Therefore for this analysis, we will focus solely on benchmarks from competitive auctions with significant premiums over reserve and where final auction prices have been determined by competition, i.e. where the auctions that have been competitive in both bands concerned. To assess competitiveness of an auction, we look at the premium of final prices over reserve prices, choosing an arbitrary cut-off point of a 40%.

154. In Table 12 below we present our findings based on data from multiband auctions and in Table 13 we show the relative band values implied by separate auctions within the same country.

Table 12: Relative band values within auctions

Auction	800MHz/900MHz	Sub-1GHz/1800MHz	1800MHz/2.1GHz
Hong Kong 2011*	0.8	-	-
United States 2008	-	-	3.0

* Frequencies in the 850MHz band and the 900MHz band

155. There are few benchmarks of multi-band auctions where bidding for both bands has been competitive and the final prices in both bands lie above the respective lower bounds of our valuation ranges. The results from the Hong Kong auction suggest that spectrum in the 900MHz band is worth 20% more than spectrum in the 850MHz band. The US 2008 benchmark, where spectrum in the PCS 1900MHz and AWS 2.1GHz bands was sold in the same auction, suggests that PCS 1900MHz spectrum is worth three times as much as AWS 2.1GHz spectrum.

156. These relative band values in Table 12 above are not consistent with the ratios suggested by our valuation ranges in Section 2.2.7, nor with those suggested by technical and business modelling in Annex C. The ratio established in Hong Kong may simply reflect the fact that the 850MHz band is a CDMA band while the 900MHz band is standardised as a mobile band globally, offering a greater range of technological options. The US results may be driven by factors that are very different from the relative technical merits of the two bands, given that the PCS band does not obviously have superior propagation characteristics to the AWS band.[52]

157. In Table 13 below, we present the relative values suggested by separate auctions in same country. The years in which the respective awards took place are shown in brackets.

[52] The PCS band in the US comprises frequencies 1850-1910MHz paired with 1930-1990MHz

The AWS band in the US comprises frequencies 1710-1755MHz paired with 2110-2155MHz.

Table 13: Relative band values across auctions within the same country

Country	Sub-1GHz/1800MHz	Sub-1GHz/2.6GHz	1800MHz/2.1GHz	1800MHz/2.6GHz
Netherlands (2012/1998)	1.5	-	-	-
Netherlands (1998/2000)	-	-	0.2	-
Canada (2001/2008)	-	-	0.5	-
Australia (2000/2001)	-	-	1.4	-
Hong Kong (2011/2009)	6.7	5.9	-	-
Hong Kong (2009/2009)	-	-	-	0.9
United States 700MHz/1900MHz (2008-2011/2005-2008)	1.9	-	-	-
United States 1900MHz/2.1GHz (2005-2008/2006-2008)	-	-	3.4	-

158. There have been numerous auctions in the United States where 700MHz, 1900MHz and 2.1GHz spectrum has been sold. We consider the 700MHz auctions in 2008 and 2011 to be the most comparable with sub-1GHz spectrum in Europe (as discussed in Section 2.2.3). We calculate the average relative value using prices achieved in the 2008 and 2011 700MHz auctions and prices achieved in 1900MHz auctions that took place around the same time (2005-2008). Similarly, when deriving a relative value between 1800MHz and 2.1GHz spectrum we calculate average relativities using prices achieved in auctions during (2005-2008).

159. The Dutch and the US auctions suggest that the relative value of sub-1GHz to1800MHz spectrum is 1.5 and 1.9 respectively. This is roughly consistent with our conclusions in Section 2.2.7. The same figure implied by the Hong Kong auctions however suggests that sub-1GHz spectrum worth substantially more than 1800MHz spectrum. However, as we have discussed in paragraph 73 above, the Hong Kong benchmark is not a good representation of market value in the UK, and therefore the relative band value derived from this Hong Kong auction result is unlikely to provide an accurate reflection of relative band values.

160. The results in Table 13 suggest a wide range of relative values for 1800MHz/2.1GHz. In the Netherlands and Canada, 2.1GHz spectrum sold for higher prices than 1800MHz spectrum. However, the Dutch 3G auction took place around the time of the telecoms bubble, and 3G prices in the Netherlands may thus be inflated relative to 1800MHz prices. In the Canadian AWS auction, a significant amount of spectrum was reserved for new entrants. This resulted in intense competition for unreserved spectrum amongst the incumbents, which drove up prices. The value difference of 1800MHz and

2.1GHz spectrum in Canada, may therefore be due in some degree to this considerable difference in competitiveness conditions. The relative band value of 1800MHz to 2.1GHz suggested by the US auctions is 3.4, which is comparable to that derived from the US multiband auction benchmark in Table 12.

161. The 2.6GHz and 1800MHz auctions in Hong Kong in 2009 suggest that 2.6GHz spectrum is of higher value than 1800MHz. We note that the 1800MHz auction in Hong Kong in 2009 was of a 1800MHz expansion band where six lots of 2x1.6MHz were auctioned. The 1800MHz benchmark from Hong Kong may therefore not be fully representative of market value of the band.

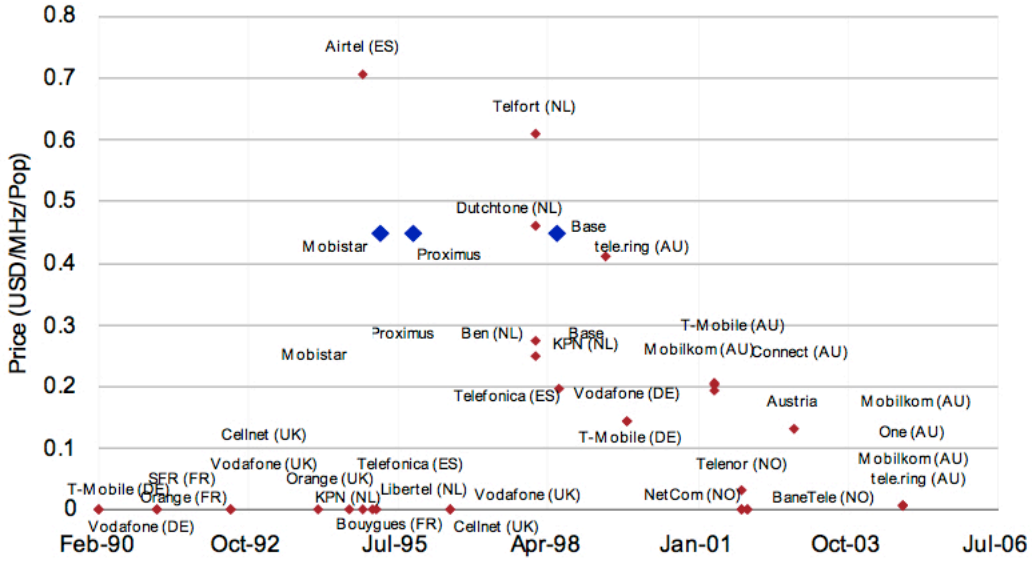
3 Licence renewal fees

162. Most spectrum regulators in the world licence spectrum for a fixed term. When licences expire, a regulator may choose to re-assign the spectrum or renew the licence for another term.

163. This renewal term may be short in some cases where the regulator extends the existing licence term so as to align the availability of spectrum in different bands. This may be done in order to allow these different bands to be auctioned off in a single multiband process. This was the case in Ireland and the Netherlands where 900MHz licences had been extended and included in multiband auctions in 2012. In Ireland, Vodafone's and O2's licences were extended for a period of just over 20 months, whilst in the Netherlands the 900MHz licences were renewed for just under three years.

164. Another type of renewal process is where licences are being renewed automatically for a given period of time unless they are explicitly terminated. This is the case in Belgium, for example where 2G licences were issued for an initial term of 15-years and automatically renewed for successive 5-year periods unless otherwise terminated by the regulator. In 2010, the law was changed to introduce a new fee for renewal to ensure optimal use of the spectrum. A legal battle followed with operators challenging the right of the regulator to charge this new fee, given that the licences had already been automatically renewed by the time the law came into effect and that the initial authorisation fee on issue of licences in 1995 and 1998 were amongst the highest in Europe (see Figure 13). The operators also challenged the level of this new fee. The case was eventually referred to the European Court of Justice who found in favour of the Belgian regulator. Further legislation was introduced to establish automatic renewal of the licences every five years until 2021, and a new fee for such renewal being payable upfront (see Annex B for more details).

Figure 13: Prices paid for 2G authorisation in Western Europe



Source: Analysys Mason and Hogan and Hartson, 2010, 'Future regulation of wireless access in the 790MHz-3400MHz spectrum bands', Report for BiPT.

165. In other cases, the regulator may renew the licence for a longer term of at least 10-years to allow existing operators to continue operations and provision of services to consumers. Regulators might opt for a licence renewal process instead of spectrum re-assignment if there are concerns that the reassignment might disrupt business continuity and consequently service provision to consumers. In addition, regulators may also decide not to re-assign spectrum in cases where they would normally use an auction, but where there is likely to be little competition for spectrum. In New Zealand licences for 800MHz and 900MHz spectrum were renewed in 2012 for a new licence term of 20-years. In Australia licences in the 800MHz and 1800MHz bands are set for renewal in 2013 for 15 years. In Canada licences in the 800MHz and 1800MHz bands have been initially renewed for five years in 2001 then later extended to a term of 10 years following a change in licencing regime proposed in 2002. In 2011, cellular and all PCS licences including those that were acquired via auction in 2001 were renewed for a term of 20 years.

166. Where regulators decide to renew licences instead of reassigning them pricing becomes an important spectrum management tool to ensure efficient use of spectrum. In these cases, regulators normally try to set renewal fees reflecting market value to ensure that the operators who are utilising the frequencies are paying a fair market value for the use of a scarce public resource.

167. Yet, any estimates of market value necessarily come with error bounds and uncertainties, and renewal fees are often lower than spectrum value determined via auctions (Section 2) and spectrum trades (Section 4).

168. This section considers case studies of market value renewal fees set by regulators. Our case studies include Australia, Belgium, Canada, France, Ireland, the Netherlands; and New Zealand.

169. Regulators may have different approaches to estimating the market value of spectrum. In Section 3.1 below, we discuss the different methodologies adopted by regulators to estimate market value and the fee structures in these countries. In Section 3.2 we present the benchmarks of market value reflecting renewal fees. All benchmarks are presented in 2013 Sterling per MHz per capita for a 20-year licence term. We have converted prices to Sterling, adjusted for inflation and licence duration differences with the same data and methodology as that set out in Section 2.1.1.

170. Full case studies of each of the countries considered here can be found in Annex B.

3.1 Approach to renewal fees

171. Table 14 below categorises the countries covered by our case studies in terms of the duration of the renewal and the structure of the renewal fees. There is an obvious split with regards to short versus longer term renewals, with licences being renewed either for a term of 15 years or more, or for 5 years or less. Regardless of duration, both one-off fees and on-going annual fees have been used.

Table 14: Licence renewal terms and charge structure

	One-off fee	On-going (annual) charge
5 years or less	Netherlands, Belgium*	Ireland
15 years	Australia	France
20 years	New Zealand	Canada

* Automatic renewal

172. Both annual fees and upfront one-off fees can, but need not be set at a level that reflects market value, and there is no presumption that the type of fee indicates the likelihood of it reflecting market value. Instead, it is necessary to consider the methodology used to estimate spectrum value.

173. Unfortunately, information about the specific approaches used by regulators to establish the level of renewal fees is not easily available. In the case of Canada, Ireland, France and Belgium, it is not clear from our research how the value of spectrum was estimated by the regulator when setting renewal fees. However, as discussed above, in Belgium, the renewal fee was introduced to encourage optimal use of scarce resources, which would suggest that it should reflect the opportunity cost of spectrum.

174. In Ireland, the renewal fees were set relative to the sums operators paid for initial authorisations. ComReg adjusted the original sums for inflation using the Consumer Price Index in Ireland and differences in licence duration terms. ComReg noted that its decision on the renewal fee is consistent with its

statutory requirements, which include setting a fee to ensure optimal use of spectrum.[53] As in the case of Belgium, this would indicate that fees reflect opportunity costs.

175. In France, the original proposal for the GSM licence renewal fee was a 5% progressive levy on annual turnover. This fee was considered too high and subsequently replaced by a fixed fee of €25 million plus an annual 1% charge on GSM service revenues.[54] In setting this revised fee, ARCEP noted that it is set in proportion to the benefits enjoyed by the operator from the use of a scarce public resource.[55] Though not a direct reference to market value, this approach appears to be aimed at capturing the value of spectrum. The mobile operators accepted this revised fee. Subsequently, in 2008, the fixed component of the fee was updated to a per-kHz-duplex-held annual charge.[56] In 2013, ARCEP approved Bouygues Telecom's application to liberalise its 1800MHz spectrum for 4G use. In doing so, ARCEP increased the per-kHz-duplex-held annual charge applicable to 1800MHz spectrum used to provide 4G services. We note however that 1800MHz spectrum held by the other mobile operators that is yet to be liberalised will be subjected to the existing annual charge set in 2008.[57]

176. Industry Canada notes that a licence fee should discourage hoarding of spectrum and enable the public to earn a fair return for the use of a scarce public resource. The current fee level however has been fixed since 2003. This fee was set at the average renewal fees paid by operators for renewal of their PCS and cellular licences in 2003[58]. At present, Industry Canada is looking at reviewing this fee to reflect market value.[59] This would suggest that the current fee levels do not reflect current market value for one or both the 800MHz and 1800MHz to which the renewal fees apply.

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[53] ComReg, 2011, *Interim Licences for the 900 MHz Band*, available at:

http://www.comreg.ie/_fileupload/publications/ComReg1129.pdf, accessed March 2013

[54] See B Guermazi and I Neto, 2005, *Mobile Licence Renewal, What are the Issues? What is at Stake*?, World Bank, Washington, DC, available at: https://openknowledge.worldbank.org/handle/10986/8653

[55] See http://www.arcep.fr/fileadmin/reprise/dossiers/auto-gsm/avis-redevc-200604.pdf

[56] Ministère de l'Économie, de l'Industrie et de l'Emploi, 2009, 'Décrets, arrêtés, circulaires (1/8/2009)', *Journal Officiel de la Republique Française*, available at:

http://www.arcep.fr/fileadmin/reprise/textes/decrets/2009/d2009-948-290709.pdf, accessed March 2013

[57] ARCEP, 2013, 'Décret n° 2013-238', available at:

http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000027205825&fastPos=4&fastReqId=796682653&categorieLien=id&oldAction=rechTexte, accessed April 2013

[58] Industry Canada, 2003, 'Notice No. DGRB-005-03', available at:

http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf08105.html, accessed March 2013

[59] Industry Canada, 2011, *Renewal Process for Cellular and Personal Communications Services (PCS) Spectrum Licences*.

177. New Zealand, Australia and the Netherlands relied on technical and business modelling in order to establish the level of renewal fees:

- New Zealand modelled the increase in cost that a generic operator would face in order to maintain current service levels via an LTE network if it lost 800MHz and 900MHz spectrum. This would seem to be the maximum amount that such an operator would be prepared to pay in order to obtain access to such spectrum, which may be well above the price that it would actually have to pay in a competitive market.[60]
- Australia modelled the value of 800MHz and 1800MHz spectrum to a hypothetical operator, assuming 800MHz will primarily be used for the deployment of 3G and 1800MHz for LTE services. It was further assumed that the hypothetical operator had similar characteristics to the weakest incumbent in the market. Two forms of value were modelled – cost reduction value (i.e. the reduction in infrastructure cost from the use of an additional block of spectrum) and full enterprise value comprising the NPV of the operator's profit stream from its entire business.[61]
- The Netherlands modelled the value loss to a new entrant denied early entry into the market as a result of the renewal of 900MHz licences (relative to the counterfactual of gaining access to spectrum three years later via winning spectrum in the 2012 multiband auction). The new entrant valuation was modelled for a range of different scenarios, assuming different technologies – GSM and/or UMTS - and rates of market share capture.[62]

178. Regardless of other factors that might influence spectrum value, we would expect an entrant's valuation of spectrum (such as modelled in the Netherlands) to be lower than an incumbent's valuation (as modelled in Australia and New Zealand). However, the cost reduction approach used in Australia and New Zealand is likely to produce lower valuations than those obtained when including revenue impacts. Finally, we would expect the full enterprise value modelled to yield the highest valuations, though not the entirety of this valuation may necessarily be attributed to the spectrum band concerned.

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[60] Network Strategies, 2007, *Renewal of Management Rights for Cellular Services (800/900MHz)*, Report for the Ministry of Economic Development, available at:

http://www.rsm.govt.nz/cms/pdf-library/policy-and-planning/radio-spectrum/rights-at-expiry/network-strategies-report, accessed March 2013

[61] Plum Consulting, 2011, '*Valuation of public mobile spectrum at 1710-1785 MHz and 1805-1880 MHz*', report for the Department of Broadband Communications and the Digital Economy, available at:

http://www.dbcde.gov.au/__data/assets/word_doc/0016/144223/Plum-Consulting-Valuation-of-public-mobile-spectrum-at-1710-1785-MHz-and-1805-1880-MHz.doc, accessed March 2013

[62] SEO Economisch Onderzoek, 2006, *Waarde GSM-spectrum*, Commissioned by the Ministry of Economic Affairs, available at:

http://www.seo.nl/uploads/media/927_Waarde_GSM-spectrum.pdf, accessed March 2013

179. Table 15 below presents the lower and upper bounds of spectrum valuations from the various technical and business models. The lower bound of the New Zealand range is set by the increase in cost from depriving an operator with 2x15MHz of 800MHz/900MHz spectrum of 2x2.5MHz of spectrum. The upper bound is the increase in cost from depriving an operator with just 2x10MHz of the same amount of spectrum. The lower bound for Australia is the cost reduction value estimate while the upper bound is the full enterprise value estimate. Finally, the lower bound of the Dutch range is set by the loss of value to the new entrant from a three-year delay to spectrum access. The upper bound is set to the value of a 15-year licence for 2x10MHz of 900MHz spectrum to the new entrant, converted into annual payments and evaluated over a three-year period. This reflects the NPV of profits from using the spectrum for the provision of GSM and UMTS services over the licence term.

180. In the case of 800MHz and 900MHz valuations, the lower bound of the Dutch model produces the lowest value estimates while the full enterprise value from the Australian model yields the highest estimates, as expected. In all cases there is a substantial difference between the lower and the upper bound estimates, with the New Zealand range falling entirely within the Dutch range. There is little overlap with the Australian estimates, on the other hand, which lie completely above the New Zealand upper bound, and almost entirely above the Dutch upper bound.

181. The higher value of 800MHz in Australia may be down to the intrinsic spectrum valuation differences in these countries. Sub-1GHz spectrum may be worth substantially more in Australia than in smaller countries such as New Zealand owing to its superior propagation characteristics. The large difference between the value of sub-1GHz and higher frequency spectrum in the Australian estimates provide some support for this explanation. However, the large gap between the valuation of spectrum below and above 1GHz would seem to be inconsistent with the relative band values based on auction data (see Section 2.4**)**, which suggests a sub-1GHz/1800MHz value of 1.7 for Australia.

Table 15: Lower and upper bound of spectrum valuations from New Zealand, Australian and the Netherlands (price/MHz/pop for a 20 year term)

		800MHz/900MHz	1800MHz
New Zealand	Lower bound	£0.13	
	Upper bound	£0.47	
Australia	Lower bound	£0.49	£0.08
	Upper bound	£1.61	£0.24
Netherlands	Lower bound	£0.10	
	Upper bound	£0.65	

3.2 Renewal fees

182. The renewal fees set by regulators in the countries covered by our case studies are presented in Figure 14 below. In the case of France, we have only included

the fixed component of annual fees in the figure below (see Annex B for more details). We note that the liberalisation of Bouygues Telecom's 1800MHz spectrum in 2013 for 4G use has seen an almost five fold increase in the applicable per-kHz-duplex-held annual charge relative to the 1800MHz annual fees applicable to 1800MHz spectrum that has not been liberalised for 4G use. It has been reported that this revised annual fee applicable to 4G use of 1800MHz spectrum has been set to reflect market value so as to encourage efficient use of spectrum.[63]

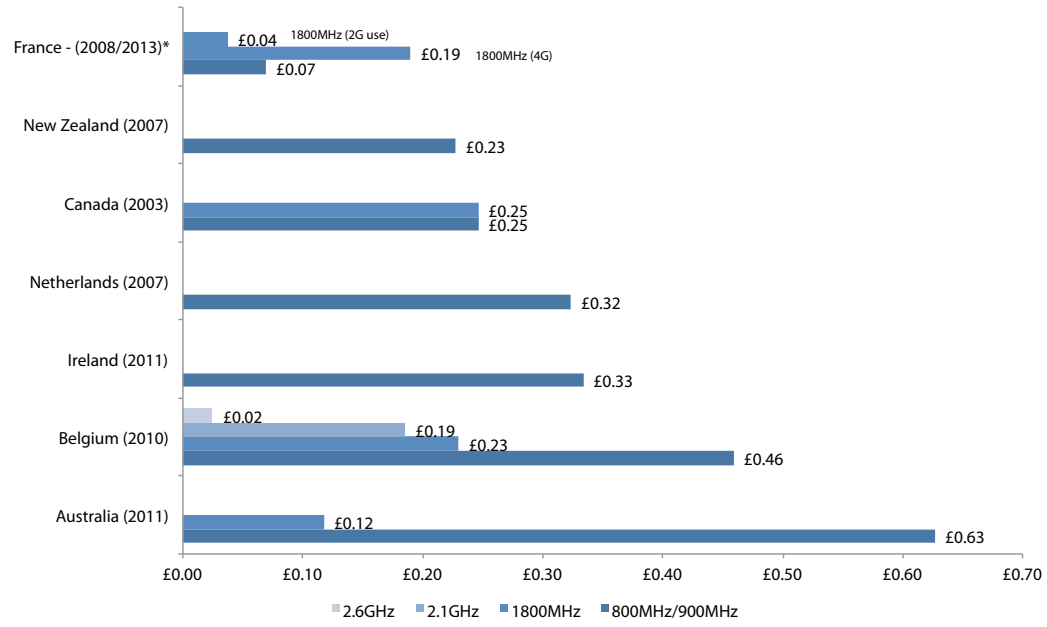
183. The variable component of the annual fees in France comprises 1% of revenues accrued from the provision of service using the spectrum concerned. We note that mobile retail revenues in France totalled £17.57 billion in 2011, of which 13% were data-related.[64] There is no information available about the split of the remaining 87% of retail revenues (£15.3 billion) between GSM and 3G, nor do we have information about GSM-related wholesale revenues. However, ignoring wholesale revenues, assuming that half of the non-data related retail revenue was allocated to GSM services, and splitting the implied 1% levy (£76.5 million) equally between 900MHz and 1800MHz spectrum will add an annual fee of £0.08 to the 900MHz and £0.04 to the 1800MHz fees where this spectrum is used for the provision of 2G services. Combining this with the 2009 fixed annual fee component will imply a total value of a 20-year licence of £0.15 for 900MHz and £0.08 for 1800MHz. This is much closer to the fee levels in Canada and New Zealand for 800MHz/900MHz and Australia for 1800MHz.

184. Amongst the remaining benchmarks, there is a range of fees for sub-1GHz spectrum of £0.23 to £0.63. We note that the renewal fees charged in the Netherlands and Ireland for the short term renewals are very similar. In the case of 1800MHz, the range is from £0.12 to £0.25.

[63] See http://www.policytracker.com/headlines/french-regulator-approves-operator-request-to-use-1800-mhz-for-4g/?searchterm=bouygues

[64] Ofcom, 2012, *International Communications Market Report 2012*, Figure 6.33 and Figure 6.38.

Figure 14: Renewal fees in case study countries (price/MHz/pop for a 20 year term)



*France – Fixed fee component only

185. In terms of setting renewal fees relative to valuations, the Netherlands, New Zealand and Australia have all set a renewal fee in the lower half of their valuation range. This is consistent with our expectation that regulators will be more conservative when setting renewal fees in reference to market value.

186. Leaving aside Australia where licences expire in 2013 and operators have not had to pay their renewal fees yet, operators in our other case study countries have accepted the renewal fees set by the regulator and gone on to renew their respective licences. We have not come across evidence that would suggest that operators in Australia are likely to reject the proposed renewal fee. This would suggest that the renewal fees in Figure 14 are consistently below operators' valuation for spectrum.

187. In terms of relative value between 800MHz/900MHz and 1800MHz spectrum, a like for like comparison of the fixed component of annual fees of 900MHz and 1800MHz that have yet to be liberalised for 4G use in France, suggest that 900MHz spectrum is worth almost twice the value of 1800MHz spectrum. This is also consistent with relative values suggested by renewal fees in Belgium.

188. Renewal fee for 800MHz and 1900MHz spectrum in Canada however are set at the same level. Canada charges the same annual fee for its cellular licences (824.04MHz-848.97MHz, 869.04MHz-893.97MHz) as it does for its PCS licences (1850 MHz to 1990 MHz). However, as noted above, Industry Canada is currently reviewing this fee level with a view to update fees to reflect market value.

189. At the other extreme, renewal fees in Australia suggest 900MHz spectrum is worth just over five times the value of 1800MHz spectrum. The large gap between fees for sub-1GHz spectrum and 1800MHz spectrum in Australia

appears to be a combination of an extremely high 800MHz value and a low 1800MHz value, as discussed above.

4 Market value indications from spectrum trades

190. There are a number of countries in the world where spectrum trading (including trading of mobile spectrum) is permitted. The UK for example has allowed the trading of mobile spectrum bands since mid-2011.

191. Spectrum trades occur rarely and the secondary market for mobile spectrum is generally rather illiquid. Trading often involves small amounts of spectrum on a regional basis, and is therefore even rarer in Europe where mobile licences have generally been awarded on a national rather than a regional basis.

192. Even where there is spectrum trade activity in the secondary market, there is often very little transparency about the commercial details of the deal. Trades involve bilateral negotiations between buyer and seller, with terms being not generally publicly known. For instance, the price Hi3G in the UK paid for EE's 1800MHz spectrum in the August 2012 spectrum trade deal is not public knowledge.

193. In addition, spectrum trades are often part of more complex deals between buyer and seller, and it is therefore difficult to establish prices even where information about the deal is publicly available. Other network assets, parts of the retail business or even subsidiary holdings in separate markets (e.g. television) are often part of the same deal, and separating out the value of the spectrum component may be impossible. In the case where regional spectrum licences are traded, details about the exact geographical coverage of the licences are sometimes not released, which means that prices cannot be related to underlying addressable market size.

194. For all of these reasons, some of the benchmarks presented in this section therefore may not provide a precise estimate of spectrum value. The US has seen the greatest volumes of mobile spectrum trades to date.[65] The regional licence structure in the US and market consolidation have both played a part in driving the volume of spectrum trading. Most of our available case studies are therefore of US spectrum trade deals. Note that in the US, spectrum licensees pay only annual regulatory fees that have been set to recover FCC's management costs rather than any AIP-based annual fees. Therefore the main cost associated with acquiring a licence should be the price of the licence payable to the seller. We have converted all prices from local currency to 2013 Sterling per MHz per capita terms using the same data treatment as described in Section 2.1.1.

4.1 700MHz spectrum trades

195. Figure 15 presents our price estimates for 700MHz trades, covering five deals that took place between 2007 and 2013.

[65] Australia has also seen a fair number of trades, mainly in frequencies of 2GHz and above. However, missing information on prices or geographical coverage of licences traded means that we are unable to include these trades.

196. AT&T has been the main buyer of 700MHz spectrum in these deals. AT&T acquired:

- C block licences (2x6MHz) covering a population of nearly 200 million from Aloha in 2007 for USD1.065 billion; [66]
- Lower D and E block licences (6MHz each) covering a population of over 300 million from Qualcomm in 2010 for USD1.1925 billion; [67] and
- B Block licences (2x6MHz) covering a population 42 million[68] from Verizon as part of a spectrum swap deal in 2013 that sees AT&T pay Verizon USD1.9 billion and transfer 10MHz of AWS spectrum in certain western markets, including Los Angeles, Phoenix, Fresno and Portland, Oregon.

197. In the two remaining deals, Verizon sold:

- an A Block licence (2x6MHz) covering a population of 10.3 million in Chicago in 2012 to Leap Wireless for USD204 million. This was part of a spectrum swap deal that also saw Leap sell Verizon PCS and AWS spectrum in various markets across the US for USD 188 million and its majority owned joint venture (Savary Island Wireless) sell AWS licences to Verizon in several markets for USD172 million;[69] and
- B Block licences (2x6MHz) covering a population of approximately 11 million to Gain Management (a private equity firm) in 2013 for USD 189 million as part of an agreement to lease the AWS spectrum Gain Management had acquired from AT&T.

198. Verizon had agreed to sell its 700MHz licences as part of the conditions to get FCC approval for its purchase of AWS spectrum from a consortium of cable companies in 2012 (see Section 4.2 below).

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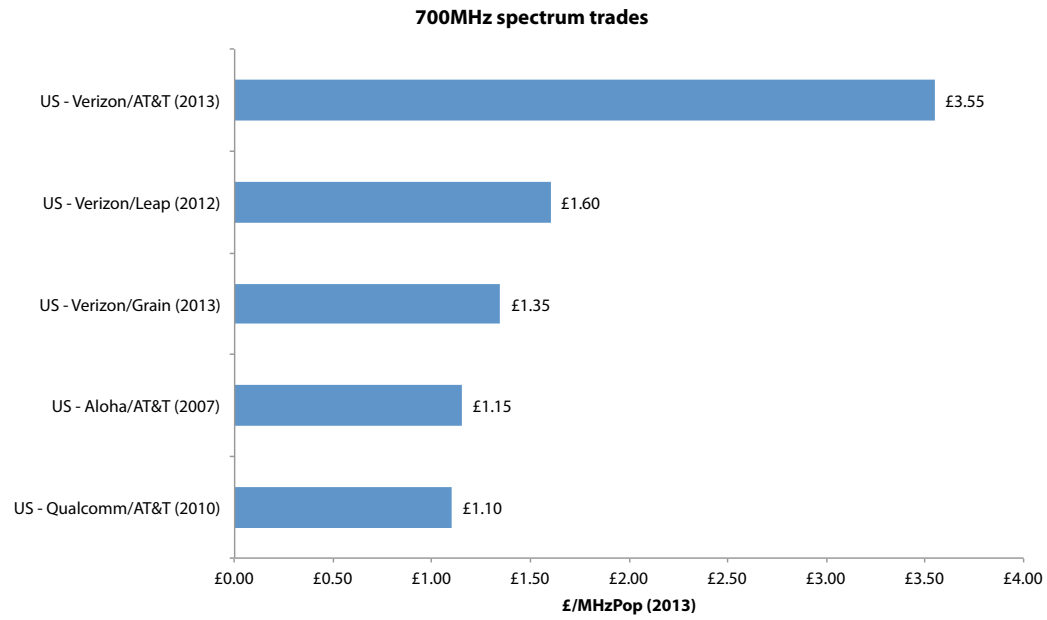
[66] See http://www.dailywireless.org/2007/10/09/att-buys-700mhz-from-aloha/

[67] See http://www.fcc.gov/document/fcc-approves-att-acquisition-qualcomm-licenses

[68] The 700MHz licences purchased covered population in 18 states including: California, Colorado, Florida, Idaho, Illinois, Louisiana, Montana, New Mexico, New York, Ohio, Oklahoma, South Dakota, Tennessee, Texas, Utah, Virginia, Washington and Wyoming.

[69] See http://leapwireless.mediaroom.com/index.php?s=13383&item=95830 and http://leapwireless.mediaroom.com/2012-08-28-Leap-Announces-Closing-of-Spectrum-Transactions-with-Verizon-Wireless

Figure 15: 700MHz spectrum trades



Note that the Verizon/AT&T deal excludes the value of AWS spectrum transferred to Verizon and the Verizon/Gain deal does not reflect the lease agreement between Gain and Verizon

199. With the exception of the Verizon/AT&T deal, we observe prices for 700MHz spectrum in the US that lie between £1.10 and £1.60 per MHz per capita. The near-national coverage of the licences AT&T acquired from Aloha and Qualcomm imply prices closer to a £1 per MHz per capita while the smaller trade deals of Verizon to Leap Wireless and Gain Management transacted closer to £1.50 per MHz per capita.

200. AT&T's purchase of 700MHz spectrum from Verizon however fetched an eye-catching price that was much higher than the prices achieved in other trades, even leaving aside the fact that the price above does not include the value of the AWS spectrum transferred to Verizon.

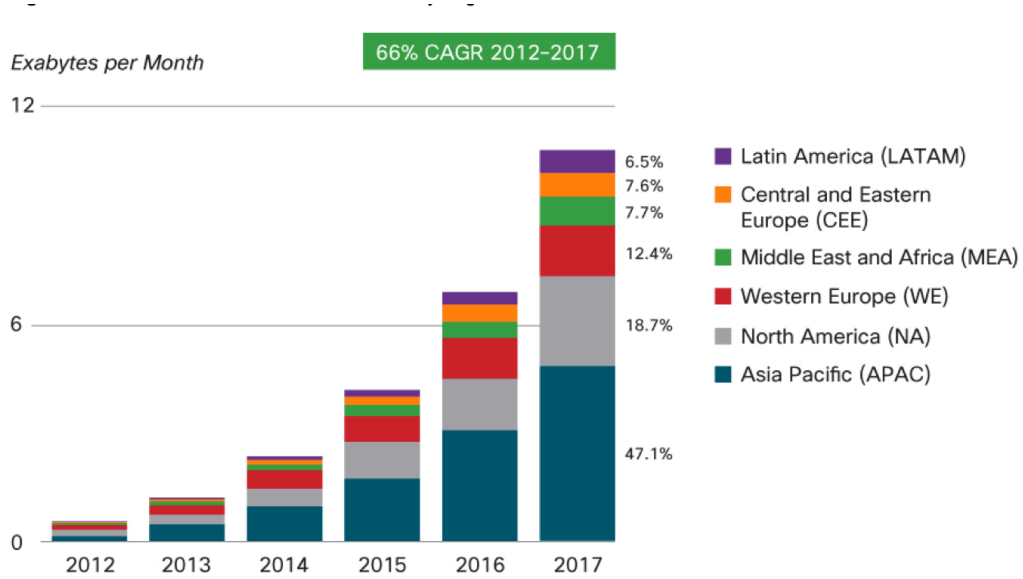
201. This suggests that Verizon would have been in a strong position to extract a substantial share of the gains from trading. Although it had committed to the FCC to sell its 700MHz licences, it only committed to do so if it received market value for the licences. At the same time, AT&T was trying to redress the imbalance in spectrum holdings that followed on from the 700MHz auction in 2008, where Verizon spent USD9.4 billion buying, USD8.5 billion MHz-pop[70] worth of licences whilst AT&T – the second largest winner - spent USD6.6bn on

[70] This refers to 1MHz of bandwidth passing one person in the coverage area in a spectrum license. This is derived by multiplying the megahertz associated with a license by the population of the license's service area. For example, a 10MHz licence covering a population of 1 million will have 10 million MHz-pop.

licences covering 2.1 billion MHz-pop, and Verizon's deals with the cable operators that brought it substantial additional AWS spectrum.

202. Indeed, since its failed attempt to merge with T-Mobile in 2011 AT&T has gone on a spectrum acquisition spree, obtaining 700MHz spectrum from a range of regional operators including, Century Tel, 700MHz LLC, Whidbey Telephone Company, Maxima International, BTA Ventures II, D&E Investment Inc, Redwood 700 Inc, Knology and Broadband Wireless Unlimited. In 2013, AT&T also acquired Alltel and its spectrum holdings in the 700MHz, 850MHz, 1900MHz bands.[71] Complementing its existing holdings in the lower 700MHz band to achieve greater regional coverage and accommodate the growing demand for data traffic might have been essential for AT&T to keep on a level with Verizon. The CTIA (the Wireless Association in the US) estimated that data traffic has doubled between June 2011 and June 2012 from 568 billion megabytes to 1.16 trillion megabytes, and Cisco forecasts further increases over the next five years (see Figure 16).

Figure 16: Cisco mobile traffic forecast 2012-2017



Source: Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012-2017

[71] It is reported that *"AT&T amassed at least $2.6 billion in spectrum deals in 2012. The most publicized transaction being its purchase of NextWave wireless, a major holder of 2.3 GHz WCS spectrum, for $600 million. But AT&T also quietly acquired numerous licenses (mostly 700 MHz) held by small carriers and individual licensees such as Cavalier Wireless, David L. Miller, Comsouth Cellular, Ponderosa Telephone Co., Farmers Telephone Co., McBride Spectrum Partners and CenturyTel Broadband Wireless. AT&T's CEO, Randall Stephenson, recently confirmed that the company signed over 50 spectrum deals in 2012 and intends to do more in 2013."* – see http://www.smartcommllc.com/wireless-blog/2013/1/smartcomm-sees-an-active-secondary-market-for-spectrum-licenses.aspx. AT&T also bought 2.3GHz spectrum licences covering 82% of national population from ComCast, Horizon Wi-COM, San Diego Gas and Electricity Company and NextWave at the end of 2012 to boost its spectrum holdings

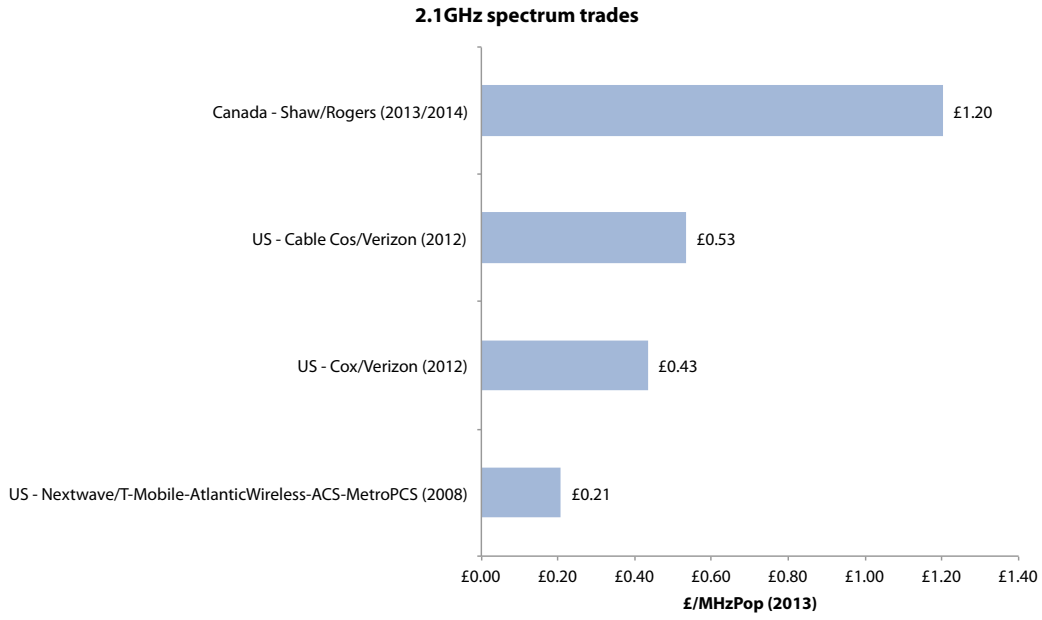
203. Verizon may well have been the only seller capable of meeting AT&T's needs quickly and effectively The B block licences bought by AT&T covered Cellular Market Areas (CMAs) – the smallest geographical division of 700MHz licences offered – including key urban areas such as Chicago, Los Angeles, Miami, Oklahoma City, and Cincinnati.

204. As expected, all the prices from the 700MHz trades in Figure 15 above lie above the prices achieved in the 2008 and 2011 700MHz auctions (see Figure 5). This confirms the view that the prices established in bilateral negotiations is higher than those that one would expect to see in a competitive market.

4.2 2.1GHz spectrum trades

205. Figure 17 shows the prices achieved in four AWS spectrum trade deals. The three US trades suggest a price range between £0.21 and £0.53. By comparison, the price agreed in Canada between Shaw and Rogers is far higher at £1.20.

Figure 17: AWS (2.1GHz) spectrum trades



206. The Canadian deal has not been completed as the terms under which Shaw acquired the spectrum in the Canadian AWS auction in 2008 prevents it from selling its spectrum to Rogers until August 2014. The agreement therefore only involves the option for Rogers to buy Shaw's AWS spectrum in September 2014. It also includes the sale of television, internet and phone provider - Mountain Cable from Shaw to Rogers, and the transfer of Rogers' one-third stake in television channel TVtropolist to Shaw.

207. Moreover, it is not clear exactly how much Rogers will pay for Shaw's AWS spectrum if it chooses to exercise its option. It is reported that Rogers will pay Shaw about CAD700 million for the entire deal, CAD400 million of which has been attributed to the purchase of Mountain Cable and CAD50 million for the

spectrum option. It is also reported that Shaw will pay Rogers CAD59 million for its stake in TVtropolist[72]. We have therefore assumed that the CAD250 million out of the CAD700 million sum that Rogers is paying Shaw that has not been accounted for is attributed to the spectrum transaction. The implied total spectrum cost including the cost of the option is assumed to be CAD300 million. Given it is not clear to us what the value of spectrum in this deal is, it would not be an appropriate to use this price point as a market value reference.

208. In 2012 Verizon bought 20MHz of AWS spectrum nationwide from a group of cable companies comprising Comcast, Time Warner Cable, Bright House Networks (jointly referred to as Cable Cos) and Cox Communications.[73] Verizon reportedly paid Cox Communications USD315m for 30 AWS licences covering a population of 28 million[74] and the Cable Cos USD3.6 billion for 122 AWS licence covering a population of 259 million.[75] In addition, the deals included an agreement under which Verizon and the cable companies would mutually market and resale each other's wireless and wireline services. Owing to these commercial arrangements as well as commitments made to the FCC the price shown above should not be interpreted as a 'pure' trade price of spectrum.

209. In 2008, NextWave sold two thirds of the AWS licences it had acquired in the 2006 auction to T-Mobile, Atlantic Wireless, ACS (Alaska) Wireless and MetroPCS. The licences reportedly comprised a total of 599 million MHz-Pop in these agreements. T-Mobile bought the largest chunk of spectrum for USD97.5 million[76] while Atlantic Wireless, ACS and MetroPCS paid a total of USD52.6 million for their licences.[77][78]

210. There is a large difference in AWS spectrum prices between the two Verizon deals and the Nextwave sale which produced a price less than half of the price

[72] See http://www.theglobeandmail.com/globe-investor/shaw-hangs-up-on-its-cellular-plans/article7340045/

[73] Cable Cos and Cox Communications together formed SpectrumCo which bought 137 licences in the 2006 AWS auction for USD2.37 billion. Cox Communications however subsequently left the SpectrumCo venture, taking its share of AWS licences with it.

[74] See http://www.fiercewireless.com/story/verizon-buy-coxs-aws-spectrum-315m/2011-12-16

[75] It is reported that, "*Comcast will receive USD2.3 billion from the sale, with Time Warner Cable receiving USD1.1 billion – both of which own around 95% of the holding company SpectrumCo. Bright House Networks, which owns 5.3% of the company, will receive $189 million. Bright House is owned by Advance/Newhouse which owns dozens of major newspapers and magazine chain Conde Nast*". See http://www.dailywireless.org/2011/12/02/verizon-buying-nationwide-aws-spectrum-from-cable/ and http://www.fiercewireless.com/story/fcc-approves-verizons-39b-aws-purchase-t-mobile-spectrum-swap/2012-08-23

[76] The licences T-Mobile acquired covered areas in Pennsylvania, Maryland, Delaware, Virginia, West Virginia, Kentucky , Ohio, Tennessee, Georgia, North Carolina, Alabama, Arkansas, Florida, Louisiana, Mississippi, Missouri, Oklahoma, Kansas, California, Puerto Rico and the U.S. Virgin Islands.

[77] These licences covered areas in Indiana, Kentucky, Illinois, Ohio, Alaska, Georgia and Florida.

[78] See http://www.fiercewireless.com/story/nextwave-offloads-aws-spectrum/2008-07-24

paid by Verizon. It is possible that the price in the Verizon deals also reflects substantial non-spectrum related aspects. Alternatively, it could be the timing of the deals that affects the traded value of AWS spectrum. The need for obtaining additional spectrum may have been much weaker in 2008, as additional spectrum was being made available in the 700MHz auction in March 2008 (where the average licence price was £1.04) and the auction in August 2008 of AWS (average licence price was £0.07) and PCS licences (at an average licence price was £0.23). It is worth noting that Nextwave had intended to sell 154 AWS licence, 30 Wireless Communication Service (WCS) licences in the 2.3GHz band and 30 licences and leases in the 2.5GHz band, but managed to offload only around two thirds of the AWS licences put up for sale.[79] Nextwave (and its WCS and AWS licences) was eventually acquired by AT&T at the end of 2012 for USD600m in cash. [80]

211. Another factor that could have influenced prices is the difference in the amount and coverage of the spectrum traded. The licences bought by Verizon covered 5.74 billion MHz-Pop while the licences sold by Nextwave in comparison totalled just 599 million MHz-Pop. In the presence of synergies and scale economies, the larger package would be more attractive and achieve a better price.

212. This explanation would seem to be contradicted by the 700MHz trades. The Verizon/AT&T trade achieved the largest price by far even though it covered only 502 million MHz-Pop compared with the 1.8 billion MHz-Pop of the Qualcomm/AT&T trade and the 2.4 billion MHz-Pop of the Aloha/AT&T trade covered. There may however been other factors that explain the high price achieved by Verizon in this deal, as explained above. Moreover, the Aloha/AT&T deal took place in 2007 at a time when the capacity needs of AT&T were probably less pressing, and the Qualcomm/AT&T deal included unpaired spectrum (the Lower Band D and E block licences) which is intrinsically less valuable.

213. Dish Network, a satellite operator, bought bankrupt TerreStar Networks, another satellite operator in July 2011. Dish was reportedly mainly interested in TerreStar's 20MHz holdings of mobile satellite services spectrum in the 2GHz band (commonly known as the "S band" or "AWS-4", specific frequency ranges from 2000MHz-2020MHz and 2180MHz-2200MHz). Dish paid USD1.375 billion for TerreStar Networks. Separately and for the same purpose, Dish bought bankrupt satellite communications firm DBSD North America, which held 20MHz of AWS-4 spectrum for USD1.4 billion.[81] Assuming that the purchase price in both acquisitions was essentially paid for gaining access to AWS-4

[79] See http://www.fiercebroadbandwireless.com/story/nextwave-selling-big-swathes-of-spectrum/2008-04-28

[80] See http://apps.fcc.gov/ecfs/document/view;jsessionid=JnMjQHVpqP1DvK2K7222GD2fzNzq2YfX11f0QfG2JnRYp1lk6gmW!-224088840!NONE?id=7022009438

[81] See http://www.assets.fiercemarkets.com/public/newsletter/fiercewireless/dishplan.pdf

spectrum, these frequencies would be valued at £0.23 per MHz per capita[82]. Dish has since gained FCC approval to consolidate these assets and use this spectrum for terrestrial use and is planning to roll out an LTE-Advance network with a wireless partner.

214. Thus, the Dish purchases of Terrestar and DBSD could be seen as an additional price point, falling within our AWS spectrum trade value range of £0.21-£0.53. However, it is worth noting that the value of AWS-4 spectrum is lower than the value of AWS spectrum. This is because of issues with protecting neighbouring satellite radio uses as well as with the availability of LTE equipment for this band. It is therefore not surprising that AWS-4 spectrum sold at the lower end of the prices achieved for AWS spectrum.

[82] This price has not been adjusted for any differences in licence duration terms as the other benchmarks in this Section have as the licence duration of MSS licences is unclear.

5 Conclusions

215. Overall, there are limitations on the available data that would clearly indicate the market value of 900MHz and 1800MHz spectrum for the UK. A number of 900MHz auctions have allocated spectrum at reserve prices with reserve prices having been set relatively low. Lack of competition in these awards means that they do not provide good indicators of market value. Similarly the 1800MHz spectrum auctions that have taken place in Europe have often not been very competitive and the frequencies have sold at or just above reserve price. There is a substantial degree of variation in the prices that have been achieved.

216. Technical modelling (see Annex C) suggests that 800MHz and 900MHz are of comparable value, and similarly that 2.1GHz spectrum may be similar in value to 1800MHz frequencies. We therefore draw on a wider sample including these bands in order to obtain auction benchmarks.

217. Table 16 gives an overview of the information we have collected. This suggests that a lower bound estimate of 900MHz market value may lie between £0.35 and £0.46 per MHz per capita in 2013 prices for a 20 year licence. Assuming that spectrum in the 800MHz band is of roughly similar value, 800MHz benchmarks suggest market value of up to £0.74. Spectrum in the 1800MHz band might be worth between £0.21 and £0.42 per MHz per capita on the same basis. Spectrum below 1GHz may be worth between 1.5 and 1.9 times as much as spectrum in the 1800MHz range.

218. Market value reflecting renewal fees set by regulators fall towards the lower end of our auction benchmark range, and the prices achieved in spectrum trades are generally above our benchmark range, as are the spectrum values derived from business modelling. In addition, Analysys Mason and Aegis Systems modelled the technical value of 700MHz to mobile operators and found the technical value of 2x10MHz of 700MHz to be £0.43 which is just above the lower bound of our auction benchmarks valuation estimate range. Overall, the various sources of evidence paint a consistent picture of market value for 900MHz and 1800MHz spectrum.

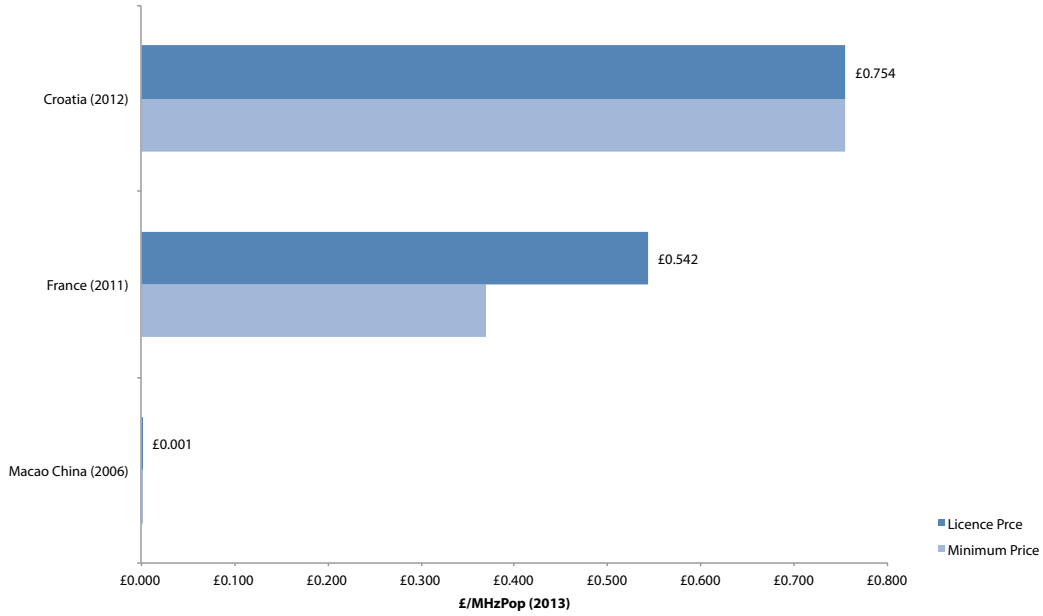
Table 16: Indicators of spectrum value

	Spectrum award benchmarks	Renewal fee benchmarks	Spectrum trade benchmarks	External evidence
900MHz	800MHz: £0.42-£0.74 900MHz: £0.35 – £0.46	800MHz and 900MHz: £0.23-£0.63	US 700MHz: £1.10 - £3.55	Analysys Mason and Aegis Systems – Technical value of 2x10MHz of 700MHz: £0.43
1800MHz	1800MHz: £0.21-£0.42 2.1GHz: £0.27-£0.54	1800MHz: £0.12-£0.25 2.1GHz: £0.19	US AWS and AWS-4: £0.21 - £0.53	-
Relative value of 900MHz to 1800MHz	1.5-1.9	800MHz and 900MHz/ 1800MHz: 1-5.4	Median of 700MHz relative to median of AWS and AWS-4 range: 2.8 Considering trades of licences covering a near national footprint: 2.3	Kerans et al: 2.5

Annex A Auction benchmarks

A.1 800MHz beauty contests

Figure 18: 800MHz beauty contests



A.2 Benchmark Samples

A.2.1 700MHz

Table 17: 700MHz auctions

Country	Award name	Date of award
United States	Auction 44	18-Sep-02
United States	Auction 49	13-Jun-03
United States	Auction 60	26-Jul-05
United States	Auction 73	18-Mar-08
United States	Auction 92	25-Jul-11

A.2.2 800MHz

Table 18: 800MHz auction

Country	Award name	Date of award
Australia	PCS 800MHz & 1800MHz Auction	20-Apr-98

Australia	PCS 800MHz & 1800MHz 2nd Auction	15-Sep-98
Australia	PCS 800MHz & 1800MHz 3rd Auction	03-May-99
Nigeria	800MHz Spectrum Auction	13-Jul-07
Brazil	2G Licences	27-Dec-07
Germany	German Multiband Auction	21-May-10
Sweden	800MHz Auction	04-Mar-11
Spain	Spanish Multiband Auction	29-Jul-11
The Korean Republic	Korean Multiband Auction	23-Aug-11
Italy	Italian 4G Auction	29-Sep-11
Portugal	Portuguese Multiband Auction	28-Nov-11
Switzerland	Swiss Multiband Auction	23-Feb-12
Denmark	800MHz Auction	26-Jun-12
Romania	Romanian Multiband Auction	29-Sep-12
Ireland	Irish Multiband Auction	15-Nov-12
The Netherlands	Dutch Multiband Auction	14-Dec-12

Table 19: 800MHz awards

Country	Award name	Date of award
Macao China	3G Auction	25-Oct-06
France	4G Award (800MHz)	15-Dec-11
Croatia	4G	29-Oct-12

A.2.3 900MHz

Table 20: 900MHz auctions

Country	Award name	Date of award
Norway	E-GSM Auction	31-Oct-01
New Zealand	Auction 5	01-Aug-02
Austria	GSM 2002 Auction	14-Oct-02

Austria	GSM 2004 Auction	11-Oct-04
Singapore	PCMTS Auction	22-Feb-08
Austria	900 MHz Auction	29-Sep-08
Denmark	900MHz	18-Oct-10
Hong Kong	850MHz, 900MHz & 2GHz Auction	03-Mar-11
Spain	Spanish Multiband Auction	29-Jul-11
Spain	Spanish Multiband 2nd Auction	10-Nov-11
Greece	Greek 900MHz & 1800MHz Auction	14-Nov-11
Portugal	Portuguese Multiband Auction	28-Nov-11
Hungary	Hungarian 900MHz Auction	31-Jan-12
Switzerland	Swiss Multiband Auction	23-Feb-12
Romania	Romanian Multiband Auction	24-Sep-12
Ireland	Irish Multiband Auction	15-Nov-12
Netherlands	Dutch Multiband Auction	14-Dec-12

A.2.4 1800MHz

Table 21: 1800MHz auctions

Country	Award name	Date of award
United States	Auction 4	13-Mar-95
United States	Auction 5	06-May-96
United States	Auction 10	16-Jul-96
United States	Auction 11	14-Jan-97
Austria	1800MHz Auction	01-Aug-97
Netherlands	2G Auction	26-Feb-98
Australia	PCS 800MHz & 1800MHz Auction	20-Apr-98
Australia	PCS 800MHz & 1800MHz 2nd Auction	15-Sep-98
United States	Auction 22	15-Apr-99
Austria	4th GSM Auction	03-May-99
Germany	GSM 1800 Auction	01-Oct-99

Australia	PCS 2000 Auction	15-Mar-00
New Zealand	Auction 3	18-Jan-01
United States	Auction 35	26-Jan-01
Canada	Additional PCS Auction	01-Feb-01
Austria	GSM 1800 Auction	07-May-01
Greece	2G and 3G	17-Jul-01
Singapore	2G Auction	11-Sep-01
Norway	GSM 1800 Auction	06-Dec-01
Israel	2G/3G Auction	26-Dec-01
Austria	GSM 2004 Auction	11-Oct-04
United States	Auction 58	15-Feb-05
Georgia	GSM 1800 MHz	15-Dec-06
Brazil	GSM Auction	07-Feb-07
United States	Auction 71 - Broadband PCS	21-May-07
Brazil	2G Licences	27-Dec-07
Singapore	PCMTS Auction	22-Feb-08
Bulgaria	Bulgaria 4th GSM License	18-Jul-08
United States	Auction 78	20-Aug-08
Singapore	1800MHz Auction	04-Feb-09
Hong Kong China	1800MHz Auction (expansion)	10-Jun-09
Germany	German Multiband Auction	21-May-10
Mexico	Auction 20	25-May-10
Denmark	1800MHz Auction	18-Oct-10
Singapore	1800MHz Auction	28-Mar-11
The Korean Republic	Korean Multiband Auction	23-Aug-11
Italy	Italian 4G Auction	29-Sep-11
Sweden	Swedish 1800MHz	17-Oct-11
Greece	Greek 900MHz & 1800MHz Auction	14-Nov-11
Portugal	Portuguese Multiband Auction	28-Nov-11
India	Resale of Quashed 2G Licences	14-Nov-12

A.2.5 2.1GHz

Table 22: 2.1GHz auctions

Country	Award name	Date of Award
United Kingdom	3G Auction	27-Apr-00
The Netherlands	3G Auction	24-Jul-00
Germany	3G Auction	18-Aug-00
Italy	3G Auction	23-Oct-00
Austria	3G Auction	03-Nov-00
Switzerland	3G Auction	06-Dec-00
New Zealand	Auction 3	18-Jan-01
Belgium	3G Auction	02-Mar-01
Australia	3G Auction	22-Mar-01
Singapore	3G Auction	11-Apr-01
Greece	3G Auction	13-Jul-01
Denmark	3G Auction	20-Sep-01
Hong Kong China	3G Auction	26-Sep-01
Czech Republic	3G Auction	07-Dec-01
Israel	2G/3G Auction	26-Dec-01
Norway	3G Auction 2	02-Sep-03
Bulgaria	3G Auction	30-Mar-05
Denmark	3G Auction 2	02-Dec-05
Indonesia	3G auction	14-Feb-06
Georgia	3G Auction	23-May-06
United States	Auction 66	18-Sep-06
Estonia	3G Tender	18-Jan-07
Nigeria	3G Auction	16-Mar-07
Norway	3G 4th licence	12-Dec-07
Brazil	3G	20-Dec-07
Canada	AWS Auction	27-May-08

United States	Auction 78	20-Aug-08
Turkey	3G	24-Nov-08
India	3G auction	19-May-10
Germany	German Multiband Auction	21-May-10
Mexico	Auction 21	25-May-10
Singapore	3G Spectrum Rights	25-Oct-10
Belgium	3G Auction	16-May-11
The Korea Republic	Korean Multiband Auction	23-Aug-11
Thailand	3G Auction	16-Oct-12
Norway	2GHz auction	20-Nov-12

A.2.6 2.6GHz

Table 23: 2.6GHz auctions

Country	Award name	Date of award
Norway	2.6 GHz Auction	13-Nov-07
Sweden	2.6GHz Auction	08-May-08
Hong Kong China	BWA Auction	22-Jan-09
Finland	2.6GHz Auction	22-Nov-09
The Netherlands	2.6 GHz Auction	26-Apr-10
Denmark	2.5GHz auction	10-May-10
Germany	German Multiband Auction	21-May-10
Austria	2.6GHz Auction	20-Sep-10
Spain	Spanish Multiband Auction	29-Jul-11
Italy	Italian 4G Auction	29-Sep-11
Portugal	Portuguese Multiband Auction	28-Nov-11
Belgium	Belgian 4G Auction	28-Nov-11
Switzerland	Swiss Multiband Auction	23-Feb-12
Romania	Romanian Multiband Auction	24-Sep-12

Table 24: 2.6GHz awards

Country	Award name	Date of award
France	4G Award (2.6GHz)	22-Sep-11

A.2.7 Other bands

Table 25: Auctions in other bands used in benchmarking analysis

Country	Award name	Band	Date of award
Hong Kong China	850MHz, 900MHz & 2GHz Auction	850MHz	03-Mar-11

Annex B Renewal fee case studies

B.1 One-off renewal fees

B.1.1 Long term renewal

New Zealand

219. Telecom NZ held a 20-year licence for 2x20MHz of spectrum in the 800MHz band (825.015MHz-845.000MHz paired with 870.015MHz-890.000MHz). This licence was due to expire in 2012. Vodafone held 2x21MHz in the 900MHz band, 2x15.2MHz worth of its licenced holdings was due to expire in 2011 (899.800MHz-915.000MHz paired with 944.000MHz-960.000MHz), with the remaining holdings to expire in 2022. Acting under Cabinet approval, the Ministry of Economic Development considered offering operators the option to renew the licences expiring in 2011 and 2012 for a further 20 years in exchange for an up-front payment. If operators chose not to renew at these terms, the spectrum would be reassigned by auction. This implies that the terms on which the licences could be renewed had to be no less attractive than the terms on which operators could expect to win spectrum in an auction, accounting of course for the uncertainty that having to bid for the spectrum rather than renewing it would entail.

220. In addition, it was decided that Vodafone and Telecom NZ should each release at least 2x7.5MHz of spectrum in the 800MHz and 900MHz bands. This spectrum would be auctioned to an entrant and not offered for renewal. Telecom NZ and Vodafone were however, given the option to divest between 2x5MHz and 2 x7.5MHz of spectrum each in the secondary market to a new entrant, in exchange for the option to renew (at the same offer price) the remainder of the 7.5MHz paired that was not offered in the secondary market transaction.[83] That is, if Telecom NZ or Vodafone failed to reach a bilateral trade agreement to sell at least 2x5MHz each to a new entrant, they would each have to give up 2x7.5MHz of spectrum for auction.

221. Network Strategies was commissioned to calculate the value of spectrum.[84] The general objective in setting the renewal fee was to maximise the value of spectrum to society. This was to be achieved by setting prices at market value in a fair, transparent and simple manner.[85][86]

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[83] Document from the Office of the Minister of Communications on 'Arrangements for the Renewal of Radio Spectrum Management Rights used for Cellular Services', available at:

http://www.rsm.govt.nz/cms/pdf-library/policy-and-planning/radio-spectrum/rights-at-expiry/cabinet-paper-arrangements-for-the-renewal-of-radio-spectrum-management-rights-used-for-cellular-services-109-kb-pdf, accessed March 2013

[84] Network Strategy's analysis was peer reviewed by Price Waterhouse Coopers.

[85] PWC -NZIER report, sections 2.1 and 2.5, on the New Zealand government's radio-spectrum website, available at:

(footnote continued)

222. Network Strategies calculated the value of spectrum using an 'incremental optimal deprival' value approach – licence value was calculated based on the incremental cost that a generic operator would have to incur in order to maintain current service levels (deploying LTE) if it were deprived of the spectrum in question based on current market conditions. The deprival value was calculated for a generic operator operating efficiently (including site planning and technology), having an average market share and traffic volumes.[87]

223. The generic operator was assumed to have 2x15MHz of 2.1GHz spectrum and an initial allocation of either 2x10MHz, 2x12.5MHz or 2x15MHz of 800MHz/900MHz spectrum. Network Strategies calculated the increase in cost to the generic operator when deprived of 2x2.5MHz of 800/900MHz spectrum. That is, scenarios of a net 800MHz/900MHz holding of 2x7.5MHz, 2x10MHz and 2x12.5MHz were modelled. The loss of spectrum increases costs in capacity constrained areas as further investment in base stations is required to support the traffic. It is worth noting here that there was no distinction in value between 800MHz and 900MHz throughout Network Strategy's analysis.

224. Network Strategies estimated that the deprival value to a generic operator per MHz paired for a 20-year 800MHz/900MHz licence ranged from NZ$2.1 million (with a pre-deprival holding of 2x15MHz of 800/900MHz spectrum) to NZ$7.8 million (with a pre-deprival holding of 2x10MHz of 800/900MHz spectrum).

225. Network Strategies cross checked its valuations against international auction benchmarks. It noted *that "The benchmarking results in a 95% confidence interval of $3.3 million to $8.0 million per megahertz pair, based on a statistical model that uses recent auction and tender results from around the world for spectrum in the 800MHz and 900MHz bands. The benchmarked result has a relatively broad confidence interval due to the limited sample data that was suitable for performing the benchmarking, but is statistically valid*".[88]

226. The New Zealand government opted for setting fees at NZ$3.8 million (excluding GST, New Zealand's VAT) per MHz paired for a 20 year term - the

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http://www.rsm.govt.nz/cms/policy-and-planning/projects/recently-completed-work/cellular-rights/past-consultation-and-documents/pwc-report-1, accessed March 2013

[86] Radio Spectrum Policy and Planning Group, 2006, 'Renewal of Management Rights for Cellular Services', available at:

http://www.rsm.govt.nz/cms/pdf-library/policy-and-planning/radio-spectrum/rights-at-expiry/renewal-of-management-rights-for-cellular-services-discussion-paper-161-kb-pdf, accessed March 2013

[87] Network Strategies, 2007, *Renewal of Management Rights for Cellular Services (800/900MHz)*, Report for the Ministry of Economic Development, available at:

http://www.rsm.govt.nz/cms/pdf-library/policy-and-planning/radio-spectrum/rights-at-expiry/network-strategies-report, accessed March 2013

[88] Network Strategies, 2007, *Renewal of Management Rights for Cellular Services (800/900MHz)*, Report for the Ministry of Economic Development, Executive Summary.

price calculated in the medium case where the pre-deprival level of spectrum was 2x12.5MHz.[89]

227. Both Vodafone and Telecom NZ accepted this offer price. Both incumbent operators also agreed respective bilateral trades to sell 2x5MHz in the 800MHz and 900MHz band to new entrant – Two Degrees Mobile. As the spectrum Two Degrees Mobile acquired from Vodafone and Telecom NZ was expiring in 2012, the Ministry of Economic Development offered Two Degree Mobiles an option to renew these frequencies under essentially the same terms as those offered to Vodafone and Telecom NZ. In late 2011, Two Degree Mobile accepted its renewal offer.[90]

Australia

228. Australian licenses in the 800MHz and 1800MHz bands are set to expire in 2013. The Australian regulator ACMA has given operators the option to renew these licences for a further 15 years. Plum Consulting was commissioned to carry out a valuation of this spectrum in order to determine the renewal price. Plum Consulting calculated both a "cost reduction value" and an operator's "full enterprise value" of spectrum. The former is the value from the reduction in infrastructure cost with the use of incrementally more spectrum while the latter is the net present value of the business' profit stream, accrued using all its spectrum holdings over the term of the licence. These two valuations form the lower and upper bounds respectively of what an operator's willingness to pay for spectrum is.

229. Plum modelled the value to a hypothetical incumbent under existing market conditions – i.e. three operators in the market. It assumed however that the hypothetical operator would have the characteristics of the weakest operator in the market. Plum assumed that 800MHz spectrum would be used primarily for the provision of 3G services while the 1800MHz would be use for the continued provision of GSM services as well as the provision of LTE services over the licence term.

230. In the case of 3G in 800MHz, Plum assumed that in addition to 800MHz, the 900MHz and 2.1GHz bands would also be used to deliver 3G services. The hypothetical operator is assumed to have a third of total available spectrum in the 800MHz, 900MHz and 2.1GHz bands and the incremental value of a

[89] Press Release on the New Zealand government's radio-spectrum website, 2007, 'Government makes offers for renewal of cellular spectrum rights', available at:

http://www.rsm.govt.nz/cms/policy-and-planning/projects/recently-completed-work/cellular-rights/media-statements/government-makes-offers-for-renewal-of-cellular-spectrum-rights-minister-of-communications-and-information-technology-media-statement-published-27-november-2007, accessed March 2013

[90] Press Release on the New Zealand government's radio-spectrum website, 2008, 'New cellular network given access to the airwaves', available at:

http://www.rsm.govt.nz/cms/policy-and-planning/projects/recently-completed-work/cellular-rights/media-statements/new-cellular-network-given-access-to-the-airwaves-minister-for-communications-media-statement-published-15-may-2008, accessed March 2013

2x5MHz in the 800MHz band is modelled. The benefits of 800MHz in providing additional capacity and as well as to provide better coverage were both modelled. Total cost reduction value was thus the sum of cost reduction value associated with both additional capacity and better coverage.

231. In the case of LTE and 1800MHz spectrum value, Plum assumed that LTE services would be provided with spectrum in the 700MHz, 1800MHz, and 2.5GHz bands. We note that 700MHz and 2.5GHz spectrum is yet to be allocated with the 700MHz and 2.5GHz auction in Australia scheduled for April 2013. Plum assumed that the 1800MHz band would provide additional capacity only and the hypothetical operator would pick up enough 700MHz spectrum in the 4G auction for coverage. Again, Plum assumed that the hypothetical operator has a third of the total available holdings in the 700MHz, 1800MHz and 2.5GHz bands and incremental value is measured against an additional 2x10MHz holding of 1800MHz spectrum.

232. The main drivers of spectrum value in Plum's model were:

a) forecast ARPU growth rates – the higher future ARPUs were the greater the full enterprise value of spectrum, ARPU growth however had no impact on the cost reduction value of spectrum;

b) data traffic growth rate – this drove network deployment cost though the increased cost would be in part mitigated by the spectral efficiencies from moving to LTE;

c) in the case of modelling 800MHz value - propagation characteristics of sub-1GHz spectrum in relation to in-building coverage; and

d) in the case of modelling 1800MHz value - available supply of 700MHz and 2.5GHz spectrum.

233. For the 800MHz band, cost reduction was estimated to be worth A$0.97 per MHz per capita for a 15 year term, whilst the full enterprise valuation was A$3.16 per MHz per capita for the same term.[91] The corresponding estimates for the 1800MHz band were A$0.15 per MHz per capita and A$0.47 per MHz per capita respectively.[92] Both sets of valuations are that of the same "medium" scenario in terms of assumptions on population, ARPU, penetration, data consumption growth trends, etc.

234. The cost reduction value of 800MHz (A$0.97) is substantially larger than that of 1800MHz (A$0.15), this is in spite of the fact that LTE modelled for 1800MHz is

[91] Plum Consulting, 2011, *Valuation of public mobile spectrum at 825-845 MHz and 870-890 MHz*, report for the Department of Broadband Communications and the Digital Economy, available at:

http://www.dbcde.gov.au/__data/assets/word_doc/0014/144221/Plum-Consulting-Valuation-of-public-mobile-spectrum-at-825-845-MHz-and-870-890-MHz.doc, accessed March 2013

[92] Plum Consulting, 2011, *Valuation of public mobile spectrum at 1710-1785 MHz and 1805-1880 MHz*, report for the Department of Broadband Communications and the Digital Economy, available at:

http://www.dbcde.gov.au/__data/assets/word_doc/0016/144223/Plum-Consulting-Valuation-of-public-mobile-spectrum-at-1710-1785-MHz-and-1805-1880-MHz.doc, accessed March 2013

considered by Plum to be more spectrally efficient than 3G modelled for 800MHz. This large discrepancy in relative cost reduction values may be attributed to the 1800MHz band being treated solely as a capacity band in Plum's analysis. In the case of 800MHz spectrum, cost reduction value due to coverage enhancements accounted for nearly 60% of total cost reduction value. Even considering 800MHz's cost reduction value due to capacity provision only – this is A$0.42 per MHz per capita in the "medium" scenario, which is still substantially higher than that of 1800MHz.

235. It is less clear why there is such a large discrepancy between the full enterprise value of 800MHz and 1800MHz given this is meant to capture the net present value of the business' profit stream. It may be the case that the cash flows modelled by Plum in the case of 800MHz are that of 3G services while in the case of 1800MHz, cash flows from LTE services are modelled. The former could be higher over the course of the renewed licence period given the current infancy of LTE service provision. In addition, it could be because the full enterprise value in the case of 800MHz is spread across a smaller base of 2x5MHz of incremental 800MHz holdings, while that of 1800MHz over a larger base of 2x10MHz of incremental 1800MHz holdings.

236. In terms of setting an appropriate renewal price, Plum's view is that operators should be prepared to pay more than the pure cost reduction value because taking the renewal option removes the uncertainty that is associated with having to win spectrum back in an auction. To account for this, Plum proposed an uplift over the estimated cost reduction value of between 25% and 50% for 800MHz spectrum, and 50% for 1800MHz spectrum. The larger uplift for 1800MHz was meant to reflect the importance of this spectrum for LTE deployment. This point was challenged by Optus who stated that increasing fees above the cost reduction value would be a deviation from the opportunity cost principle.[93]

237. Weighing the objectives of promoting efficient spectrum use and obtaining a fair value, ACMA eventually set a renewal fee of A$1.23 per MHz per capita for the 800MHz band and at A$0.23 per MHz per capita for the 1800MHz band.[94]

B.1.2 Short term renewals

Netherlands

238. 900MHz licences held by KPN and Vodafone in the Netherlands were set to expire in 2010. The Dutch Ministry of Economic Affairs - Ministerie van Economische Zaken (MEZ) considered extending the 900MHz licences so that

[93] Optus, 2013, *Regional and Remote Apparatus Licences in the 1800 MHz band (1800 MHz – a shared strategy) Issues Paper*, Submission to the Australian Communications and Media Authority, available at:

http://www.acma.gov.au/webwr/_assets/main/lib550036/ifc41_2012-optus.pdf, accessed March 2013

[94] Spectrum Access Charges 2012, available at:

http://www.dbcde.gov.au/__data/assets/pdf_file/0006/146058/Direction-to-the-ACMA-under-subsection-294-2-of-the-Radiocommunications-Act-1992.pdf, accessed March 2013

they would expire at the same time as the 1800MHz licences, enabling an auction of both bands in the same process. In view of setting a renewal fee to extend the 900MHz licences for three years, the Ministry commissioned SEO Economic Research in 2006, to estimate the value of GSM spectrum in the 900MHz band.

239. There was concern about the potential detrimental impact on potential market entrants from extending the licences as not offering 900MHz spectrum upon expiry of the licences might deny them early access to the market. Therefore, SEO focused on estimating the value of early access to 900MHz spectrum to a potential newcomer.[95] Continued use by the incumbent had to be worth at least the amount that a newcomer would have been prepared to get earlier access to the spectrum.

240. SEO used a discounted cash flow analysis in order to calculate the benefits to a new entrant from earlier availability of the spectrum. Varying projections of the potential market share of the entrant and likely ARPUs were used in order to generate a range of valuations. The rates of UMTS migration were forecast for two scenarios. The slow scenario assumed a UMTS penetration rate of 40% in 2010 and 90% in 2017, while the fast scenario assumed a UMTS penetration rate of 60% in 2010, 90 % in 2013 and 100% in 2015.

241. SEO found that an entrant would derive the greatest value when using the spectrum for the provision of GSM and 3G services. The net present value of the entrant's cash flows over a 15-year term for a 2x10MHz licence used to provide GSM and 3G services ranged from €46 million to €155 million. Based on these estimates, the value of the licence over a 3-year period to a new entrant was derived to be €0.70 million to €2.39 million per MHz paired per year.

242. SEO then calculated the loss in value to the new entrant business case from a three year delay to spectrum access. This was estimated at €0.36million to €5 million per MHz paired per year. The value of a 15-year licence used over a 3-year period however was estimated to be just €2.39 million per MHz paired per year. Therefore, even if the 900MHz licences were not extended and these frequencies were available in 2010, the new entrant would not be able to pay more than €2.39 million for early access to 900MHz spectrum. Therefore, SEO recommended that the loss in value to the entrant from a three year delay to 900MHZ spectrum access should range between €0.36 million to €2.39 million per MHz paired per year.

243. SEO considered that the most reliable estimates for the value loss from not having earlier access to spectrum were between €0.36 million and €2.39

[95] SEO Economisch Onderzoek, 2006, *Waarde GSM-spectrum*, Commissioned by the Ministry of Economic Affairs, available at:

http://www.seo.nl/uploads/media/927_Waarde_GSM-spectrum.pdf, accessed March 2013

million per duplex MHz per year.[96] The MEZ set a renewal price of €3.21 million per MHz duplex for the three year extension.[97]

Belgium

244. 900MHz licences were assigned by a Royal Decree in 1995 and 1800MHz licences by another Royal Decree in1997. Licences were for an initial term of 15-years and there was automatic renewal of these licences for a period of five years at a time unless otherwise notified by the regulators within two years of licence expiry. The three mobile operators each paid an initial authorisation fee of BEF 9 billion. In addition, they were subjected to annual fees of BEF10 million for the management of the licence and BEF 1 million per duplex radio channel to cover the regulator's monitoring and frequency coordination costs.

245. In 2010, the Belgian government passed a law[98] to introduce a new fee for renewal to ensure optimal use of the spectrum. The Belgian regulator claimed that these fees reflected the economic value of the spectrum.[99] A legal battle followed between the mobile operators and the regulator on whether the regulator had a right to charge this new fee, given their licences had already been automatically renewed by the time this law was passed and they paid significant initial authorisation fee on issue of licences in 1995 and 1997. The case was eventually referred to European Court of Justice who found in favour of the Belgian regulator.

246. The Belgian government then passed the law of the 25th January 2011, tacitly renewing the 900MHz and 1800MHz licences every five years till the 15 March 2021 and imposing the new annual fees on the licensees. This fee was to be paid in addition to on-going administrative annual charges described above. The scope of the law was broad, applying to 900MHz, 1800MHz, 2.1GHz and 2.6GHz spectrum. In the case of 2.1GHz and 2.6GHz spectrum, the law set the minimum fee level for these licences in the then upcoming auction for these frequencies. The reserve prices in the Belgian 3G and 4G auctions in 2011 were thus set by this new law.

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[96] ibid.

[97] Figures available from the Ministry of Economic Affairs, 2007, reported at:

http://www.beurs.nl/nieuws/buitenland/23007/ez-verlenging-gsm-vergunning-kost-kpn-eur-398-miljoen, accessed March 2013; see also Press Release for Netherlands Government, 2007, 'Heemskerk maakt verlenging GSM vergunningen KPN en Vodafone mogelijk', available at:

http://www.rijksoverheid.nl/documenten-en-publicaties/persberichten/2007/03/30/heemskerk-maakt-verlenging-gsm-vergunningen-kpn-en-vodafone-mogelijk.html, accessed March 2013

[98] The law of 15th March 2010 amending article 30 of the law of 13 June 2005 concerning the law of electronic communications.

[99] Belgian Constitutional Court, 2011, 'Arrêt n° 110/2011 du 16 juin 2011', available at:

http://www.hlspectrumreview.com/stats/pepper/orderedlist/downloads/download.php?file=http%3A//www.hlspectrumreview.com/uploads/file/Belgian%2520constitutional%2520court_Belgacom_2011-110f%281%29.pdf, accessed March 2013

247. These new fees were define in terms of a per MHz per month charge as follows:

a) 900MHz: €51,644 per MHz and per month. The right to use frequencies in the 900MHz band was joined to the right for frequencies in the 1800MHz band. Specifically the amount of spectrum assigned in the 1800MHz band is twice that in the 900MHz band. The annual fee for 1800MHz frequencies is therefore half that of 900MHz at €25,822 per MHz per month;

b) 2.1GHz: €20,833 per MHz and per month, although if the operator had less than 2 x 5MHz of spectrum in the band already this figure was raised to €32,000 per MHz and per month;

c) 2.6GHz: €2,778 per MHz and per month.[100]

B.2 Annual fees

Canada

248. The cellular (800MHz) spectrum licences in Canada were originally awarded via a beauty contest in 1985 respectively. Licensees had to acquire site-specific radio licences in order to operate their networks. Radio licences had to be renewed every year. Eventually, cellular licences were renewed for a five year term expiring in 2001, and renewed in 2001 for another five year term until 2006. The so-called incumbent and incumbent PCS (1900MHz) licences were awarded in 1995 and were granted with a five year term starting in 1996. Licensees also required site-specific radio licences. The incumbent PCS licences too were extended for another five year term in 2001. Additional PCS spectrum was awarded via auction in 2001 for a 10-year term.

249. The 2001 PCS licences were tradable and the licensees were not required to apply for site specific radio authorisations to operate a network. In 2002, Industry Canada proposed a new licensing regime to move the cellular and incumbent PCS licences from an apparatus-based to spectrum-based licensing regime, extending the renewal term of these licences from 5 to 10 years with a high expectation of future renewals. The new regime would also make consistent the conditions surrounding tradability of the cellular and incumbent PCS licences with those of the 2001 PCS licences as well as proposing a common fee regime for these licences.[101]

250. Industry Canada proposed a common per MHz per head of population fee for all cellular and incumbent PCS licensees to take into account the amount of

[100] SPF Economie, 2010, 'Lois, Decrets, ordonnances et reglements' of 25.03.2010, for Moniteur Belge, available at:

reflex.raadvst-consetat.be/reflex/pdf/Mbbs/2010/03/25/116013.pdf, accessed March 2013

[101] Industry Canada, 2002, *Consultation on a New Fee and Licensing Regime for Cellular and Incumbent Personal Communications Services (PCS) Licences*, available at:

http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01827.html, accessed March 2013

spectrum assigned as well as the population of the licence coverage area. Industry Canada proposed that the applicable annual fee for cellular and incumbent PCS licensees should be set at the annual fee level paid by Rogers Wireless (who had the widest network coverage across Canada) for the fiscal year of 2000/2001, i.e. for the last period of the previous term. This fee level was CAD0.052 per MHz per capita.

251. The cellular and incumbent PCS licensees opposed this for being too high. A revised fee level was determined by Industry Canada based on the total renewal fee paid by operators.[102] This led to a fee of CAD0.035 per MHz per capita in 2003.

252. It is not clear whether Industry Canada considered the renewal fees set in 2003 to be reflective of market value. When the renewal fee was set in 2003 however, Industry Canada had intended that the fee level would be reviewed and potentially revised later on. Specifically, Industry Canada noted that the Spectrum Policy Framework requires that fees should be set to reflect the estimated value of spectrum so as to promote efficient use and ensure a fair return to the Canadian public for access to a scarce resource.[103] This could suggest that Industry Canada was of the view that the 2003 fee level of CAD0.035 did not reflect market value of either one or both of the cellular and PCS bands, or that the market value might change over the period of the licence.

253. In its 2009 consultation on the renewal of cellular and PCS spectrum licences, Industry Canada noted that it was assessing the current market value of cellular and PCS spectrum. The study would include international benchmarking of fees as well as a review of prices of comparable spectrum in Canada.[104]

254. In November 2010 however, when considering the renewal process for cellular licences and incumbent PCS licence and PCS licences auctioned in 2001, the Minister of Industry, froze the renewal fee level for all these licences at the CAD0.035 level set in 2003. It is unclear whether the outcome of Industry Canada's study on market value of these spectrum bands mentioned in the 2009 consultation had been taken into account in this decision. However we note that in Industry Canada's 2011 statement on the renewal process for cellular and PCS licences, that the Minister *"may review and amend the fees*

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[102] Specifically, *"the 2003 licence renewal fees of $129,982,841 paid by these service providers. This equates to $1,053,957 per MHz nationally or $0.03512361 per person given that the 2001 census population of Canada was 30,007,094"* – see http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf08105.html

[103] Industry Canada, 2009, *Consultation on the Renewal of Cellular and Personal Communications Services (PCS) Spectrum Licences*, available at:

http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf09318.html, accessed March 2013

[104] Industry Canada, 2009, *Consultation on the Renewal of Cellular and Personal Communications Services (PCS) Spectrum Licences*, available at:

http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf09318.html, accessed March 2013

during the licence term after consulting with licensees."[105] The 2011 renewal process also saw the extension of licences from existing 10-year terms to 20-year terms.

Ireland

255. Vodafone and O2 were each awarded 900MHz licences for a period of 15-years on 16th May 1996. They each held 2x7.2MHz of 900MHz spectrum. In 2010, ComReg proposed to award 900MHz and 800MHz spectrum in a multi-band auction process. It was subsequently decided that 1800MHz spectrum should also be allocated within the same auction. 800MHz spectrum would only be available for use from 1st February 2013 while the 1800MHz licences of Vodafone and O2 were due to expire at the end of 2014, and the licence of Meteor on 12th July 2015. ComReg decided to offer 800MHz, 900MHz and 1800MHz spectrum in the auction in two time slices:

    a) First time slice running from 1st February 2013 to 12th July 2015;

    b) Second time slice running from 13th June 2015 to 12th July 2030.

256. In order to auction off 900MHz in the multiband process alongside 800MHz and 1800MHz, ComReg extended Vodafone and O2's 900MHz licences up to the start of the first time slice (31st January 2013). The renewal fees for these interim licences were set by ComReg with reference to the fees that Vodafone and O2 had paid for their initial authorisations. Specifically, in 1996, Vodafone and O2 paid:

    a) an upfront fee of €12,697,381 (IR£10m); and

    b) an annual fee of €25,395 per 200 kHz duplex channel

257. To calculate the renewal fee for the interim licences, ComReg:

    a) annualised the upfront fee of €12,697,381 to a yearly amount of €846,492 (that is €12,697,381 divided by 15 years) and adjusted this annualised amount for inflation using the Irish Consumer Price Index (CPI). The CPI had increased by 45.86% between 1996 and 2011 when the licences were renewed. The annualised sum in 2011 prices was therefore €1,234,693 for 2x7.2MHz or €34,297 per 200kHz duplex channel;

    b) adjusted the annual fee of €25,395 per 200 kHz duplex channel. for inflation of 45.86% bringing it to €37,041 in 2011 prices; and

    c) combined the annualised upfront fee yielding a total of €71,338 per 200kHz duplex channel or €2,568,168 for a holding of 2x7.2MHz.

258. In its statement on appropriate fees for these interim licences, ComReg noted that its decision on the renewal fee is consistent with its statutory

[105] Industry Canada, 2011, *Renewal Process for Cellular and Personal Communications Services (PCS) Spectrum Licences*, available at:

http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10003.html, accessed March 2013

requirements, which include setting a fee to ensure optimal use of spectrum.[106]

259. In November 2012, ComReg updated the applicable CPI level for the adjustments of the annual fees, increasing the renewal fee to €73,064 per 200 kHz duplex channel per annum. [107]

France

260. Orange and SFR's GSM licences in France were originally awarded for a 15-year term on 25th March 1991, and were due to expire in March 2006, while Bouygues Telecom's GSM licence was due to expire at the end of 2009. ARCEP began its consultation process on the renewal of Orange and SFR's GSM licences in July 2003.[108] Amongst the issues raised alongside the licence renewal were refarming of the 900MHz and 1800MHz bands, liberalisation of 900MHz and 1800MHz for UMTS and extending the coverage obligations of the licences to improve UMTS coverage in France.

261. In 2006, ARCEP renewed SFR and Orange's GSM licences for another 15 years. It was deemed at that time that refarming was not necessary due to the lack of interest by a potential fourth player for entry into the market. SFR's and Orange's licences were also liberalised for UMTS use and ARCEP extended the coverage obligation of these licensees from 90% to 99% population coverage by the end of 2007.[109] ARCEP set an annual fee for renewal comprising a fixed component of €25 million and a variable component of 1% of turnover attributable to the use of the GSM frequencies.[110]

262. In setting this renewal fee, ARCEP noted that it is set in proportion to the benefits enjoyed by the operator from the use of a scarce public resource.[111] Though not a direct reference to market value, this approach appears to be aimed at capturing the value of spectrum for the public purse.

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[106] ComReg, 2011, *Interim Licences for the 900 MHz Band*, available at:

http://www.comreg.ie/_fileupload/publications/ComReg1129.pdf, accessed March 2013

[107] ComReg, 2012, *Proposal to Extend the Duration of Existing Interim GSM 900 MHz Rights of Use*, available at:

http://www.comreg.ie/_fileupload/publications/ComReg12127.pdf, accessed March 2013

[108] ARCEP, 2003, *Consultation publique sur le renouvellement des autorisations GSM*, accessed March 2013:

http://www.arcep.fr/uploads/tx_gspublication/conspub-re-nouv-gsm.pdf

[109] See http://www.arcep.fr/index.php?id=7183&L=1

[110] ARCEP, 2006, 'Décision n° 06-0140', available at:

http://www.arcep.fr/uploads/tx_gsavis/06-0140.pdf, accessed March 2013

ARCEP, 2006, 'Décision n° 06-0239', available at:
http://www.arcep.fr/uploads/tx_gsavis/06-0239.pdf, accessed March 2013

[111] See http://www.arcep.fr/fileadmin/reprise/dossiers/auto-gsm/avis-redevc-200604.pdf

263. In 2006, ARCEP launched a consultation on the renewal of Bouygues Telecom's GSM licence and subsequently in December 2007 issued a decision that Bouygues Telecom's licence would be renewed under the same conditions as those of Orange and SFR.[112] However, when actually renewing Bouygues Telecom's licence and liberalising the spectrum in 2008 ARCEP revised the annual fees charged. Specifically, ARCEP decided that all renewals from 1st January 2006 were to pay an annual fee comprising:

    a) a fixed component of €1,068 per kHz duplex for 900MHz frequencies and €571 per kHz duplex for 1800MHz frequencies;

    b) a variable component of 1% of turnover arising from the utilisation of 900MHz and 1800MHz frequencies[113]

264. It is not entirely clear why ARCEP revised the fixed component of its annual fees to be defined in terms of per kHz duplex, but we note that based on the operators' respective spectrum holdings in 2008, €1,068 per kHz duplex for 900MHz and €571 per kHz duplex for 1800MHz would amount approximately to €25 million per operator. Perhaps this was done in order to facilitate refarming of 900MHz and 1800MHz spectrum in case of a fourth operator entering the market. Existing operators had agreed to such refarming as part of their conditions for GSM renewal and liberalisation. Free Mobile entered the market in 2009 by winning a 3G licence, and subsequently obtained GSM spectrum from the incumbents.

265. In 2012 Bouygues Telecom applied to ARCEP liberalised their 1800MHz spectrum for 4G use. In 2013, ARCEP approved application conditional upon Bouygues giving up some spectrum in the 1800MHz band (at least 2x2.8MHz) so it will hold not more than 2x23.8MHz, the same amount as the other mobile operators in France. In addition, Bouygues must further reduce its spectrum holdings in the 1800MHz band to 2x20MHz by May 2016.[114] The freed up spectrum will be made available to new entrant Free Mobile.

266. ARCEP also increased the per-kHz-duplex-held annual charge applicable to 1800MHz spectrum use for the provision of 4G services. The following annual fee is applicable to Buoygues 1800MHz licence if used for 4G:

    a) a fixed component of €3,231 per kHz duplex;

    b) a variable component of 1% of turnover arising from the utilisation of 1800MHz frequencies[115]

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[112] ARCEP, 2007, 'Décision n° 2007-1114', available at:

http://www.arcep.fr/fileadmin/uploads/tx_gsavis/07-1114.pdf, accessed March 2013

[113] ARCEP, 2008, Notice of 16 January 2008, available at:

http://www.arcep.fr/fileadmin/reprise/dossiers/auto-gsm/avis-160108-redevances-gsm.pdf

[114] ARCEP, 2013, 'Décision n° 2013-0514', available at:

http://www.arcep.fr/uploads/tx_gsavis/13-0514.pdf, accessed April 2013

[115] ARCEP, 2013, 'Décret n° 2013-238', available at:

(footnote continued)

267. This represents a five fold increase in the fixed component of the annual fee relative to that of 1800MHz spectrum that is not liberalised for 4G use. It has also been reported that this revised fee is set to reflect market value so as to encourage efficient use.[116] We note however that 1800MHz spectrum held by the other mobile operators that is yet to be liberalised will be subjected to the existing annual fees that were set in 2008. The annual fees applicable to 900MHz licences have also remain unchanged.

268. Bouygues accepted these terms set by in April 2013 and Bouygues can make use of the spectrum for 4G from 1st October.

http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000027205825&fastPos=4&fastReqId=796682653&categorieLien=id&oldAction=rechTexte, accessed April 2013

[116] See http://www.policytracker.com/headlines/french-regulator-approves-operator-request-to-use-1800-mhz-for-4g/?searchterm=bouygues

Annex C Frequency band impact on spectrum value

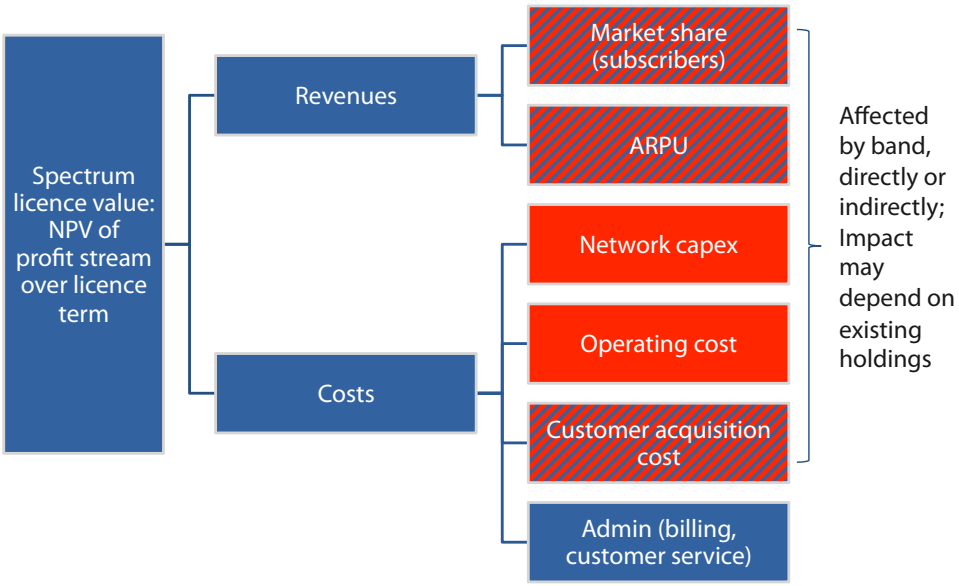
269. In this Annex, we review the evidence available on the impact of frequency band on spectrum value. We will look at the value drivers of spectrum, the impact of frequency band on network costs and on overall spectrum value.

C.1 Spectrum value drivers

270. The value of spectrum for an operator is determined by the discounted stream of profits – revenues minus costs – that can be generated from the use of the licensed frequencies over the duration of the licence (including, where appropriate, the strategic value associated with denying access to spectrum to competitors). The two main drivers of revenue streams are the operator's market share of subscribers and the average revenue per user. Costs comprise network roll out costs (capital expenditure), operating expenditure, customer acquisition costs and general administrative costs (including billing and customer service). This is illustrated in Figure 19 below.

271. In addition, we note that an operator may have strategic value for spectrum associated with the gains from preventing new entry or stifling the expansion of an existing competitor. Such strategic value may therefore be accrued from restricting a competitor's access to spectrum. We note however that in our review of business models, strategic value is typically not modelled and we have not consider the impact of strategic value in the remainder of this annex.

Figure 19: Spectrum value drivers

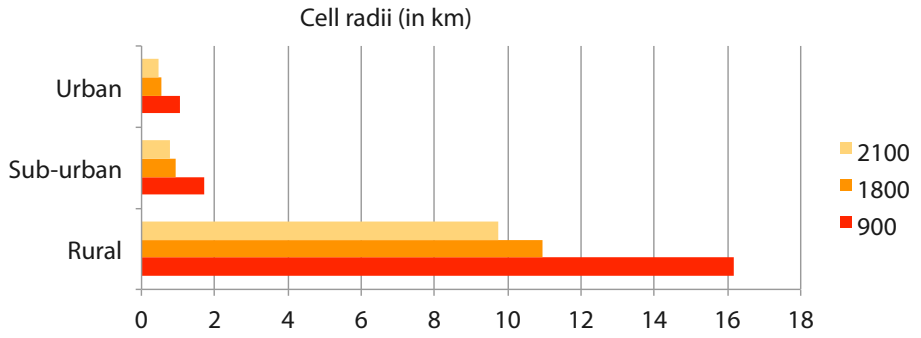


272. With the exception of administrative costs (billing and customer services), all of the revenue and cost components are affected either directly or indirectly by the specific frequencies used. Before discussing what impact the specific band used for the provision of mobile services has on the drivers of spectrum value, we should note that an operator's spectrum valuation also depends on its existing spectrum holdings, network setup and topology. The band-specific impact may therefore vary between operators.

273. The specific frequencies used have a direct impact on network roll out cost (capex) as well as operating cost (opex) because the propagation characteristics of the spectrum used determines the number of cell sites required to provide a certain level of coverage and handle a certain amount of traffic. The number of sites will in turn determine the cost of backhaul. In general terms, lower frequencies have more favourable propagation characteristics, which means that fewer cell sites are needed to cover a given area. In-building coverage is also improved.

274. For example, a study for ComReg on UMTS network design and cost prepared by Villicom in 2009[117] estimated that building a UMTS network covering 95% of the population and 80% of the area of Ireland would require roughly half the number of sites if 900MHz spectrum rather than 1800MHz spectrum were used. To deploy a UMTS network with 2.1GHz spectrum would in turn require roughly 20% more sites than using 1800MHz spectrum. The decrease in the number of cell sites is accompanied by an increase in the capacity of the links between the sites and the mobile switching centres, as each site will handle a greater amount of traffic. For a UMTS900 network, UMTS1800 and UMTS2100 network respectively, five, three and two E1 links are required per site.

Figure 20: Vilicom estimate of network roll out requirements in 900MHz, 1800MHz and 2.1GHz



	Cell sites	E1s for linking base stations
900MHz	533	2665
1800MHz	1013	3039
2100MHz	1243	2486

Source: Vilicom 2009, op cit.

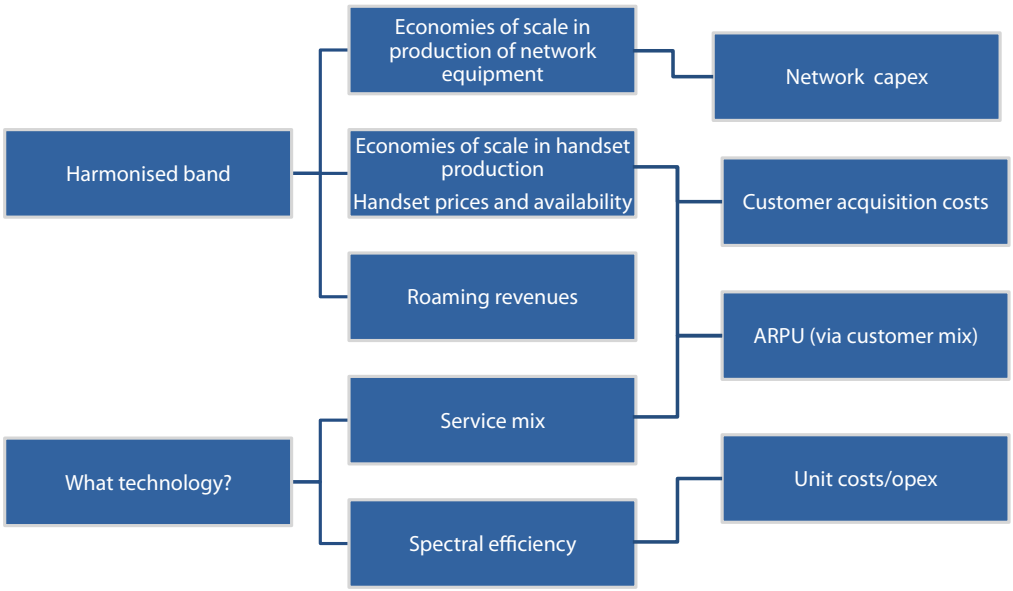
275. Other value drivers (shaded in Figure 19 above) such as customer acquisition cost, ARPU and subscriber market share are affected by whether the use of a frequency band is internationally harmonised. Harmonised bands have the advantage that operators will benefit from economies of scale for both

[117] Vilicom, 2009, *UMTS Network Design & Cost, Estimation for National UMTS900, UMTS1800 & UMTS2100 Networks*, prepared for ComReg.

handsets and network equipment (see Figure 21 below). A greater range of handsets and network equipment at lower prices is available for harmonised bands. This would reduce network roll-out costs. Lower handset prices would reduce customer acquisition costs as lower handset subsidies would be required. International standardisation also offers access to roaming revenues, increasing ARPUs. Being able to offer a greater range of handsets may affect customer mix and thus ARPUs.

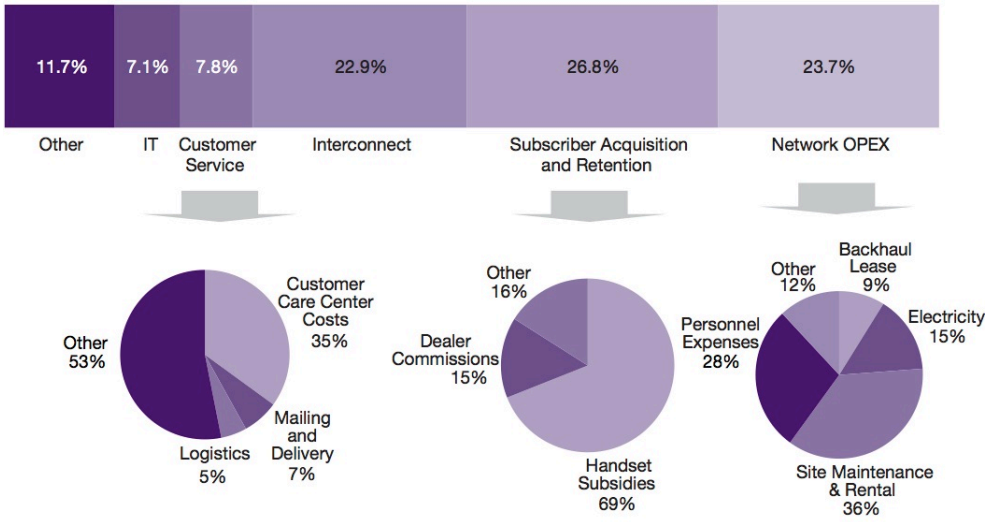
276. In addition to whether or not a band is harmonised, the specific technological standard(s) that may be used in that band also affect spectrum value. The specific technology in use has an impact on service mix, which in turn affects ARPUs and potentially customer acquisition costs. For instance, an operator who is unable to offer 4G services may face lower (and declining) ARPUs and fail to attract subscribers with high data usage. This effect may become more pronounced in the future when there is a significant discrepancy between the quality of services offered by a 3G network compared to 4G networks. Therefore the relative benefits of a particular technological standard over another may change over time. Last but not least, different technological standards may vary in terms of their spectral efficiency which in turn may affect operating expenditure. Figure 21 provides a summary of these effects.

Figure 21: The impact of harmonisation on spectrum value



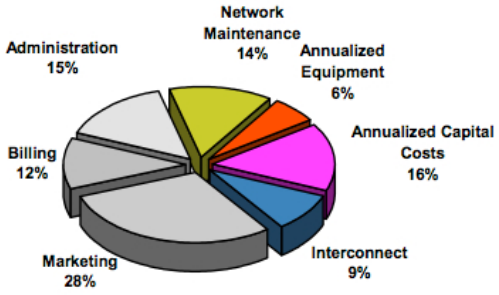
277. Below, we will focus on the impact of varying propagation characteristics of spectrum on spectrum value differences between different frequency bands, not least because network costs (both the capital expenditure associated with roll-out and the ongoing operating expenditure) are a major component of an operator's total cost (see Figure 22 and Figure 23 below).

Figure 22: Typical opex breakdown for a European mobile operator (% of total opex)



Source: CapGemini, Telecom & Media Insights Issue 42, 'Quest for Margins: Operational Cost Strategies for Mobile Operators in Europe'. Available at: http://www.capgemini.com/m/en/tl/tl_Operational_Cost_Strategies_for_Mobile_Operators_in_Europe.http://www.capgemini.com/m/en/tl/tl_Operational_Cost_Strategies_for_Mobile_Operators_in_Europe.

Figure 23: Cost structure for US mobile operators in the mid 90's



Source: Giles, T, et al, 2004, 'Cost Drivers and Deployment Scenarios for Future Broadband Wireless Networks – Key research problems and directions for research'. Available at: www.ictregulationtoolkit.org/en/Document.2897.pdfwww.ictregulationtoolkit.org/en/Document.2897.pdf

C.1.1 Propagation characteristics and impact on site requirement

278. Table 26 below presents the cell radii of different mobile frequency bands relative to the cell radius of an 1800MHz network (for the same geotype) based on a number of technical studies.

Table 26: Normalised relative cell radii of different frequency bands

Source	800MHz	900MHz	1800MHz	2.1GHz	2.6GHz
External sources quoted by Analysys Mason (as part of Hi3G's confidential response to the January 2012 Consultation[118])	2.0	1.9	1.0	-	-
Vilicom(2009) for ComReg[119]	-	1.5-1.9	1.0	0.8-0.9	-
PA Consulting 2010 for the Dutch Ministry of Economic Affairs[120] –	1.4-3.8	1.3-3.6	1.0	0.9-1.0	0.7-0.9

Note: cell radii vary from dense urban to rural geotypes

279. There are some discrepancies across the studies in terms of relative cell radii for the same band. Nonetheless all the various sources consistently show that:

- sub-1GHz spectrum supports larger cell radii, which means that fewer cells are needed for reaching a given coverage level;
- the 800MHz and 900MHz bands are of a similar order in terms of cell radius; and that
- the 1800MHz band and the 2.1GHz band are of a similar order in terms of cell radius.

280. In Hi3G's confidential response to the January 2012 consultation, Analysys Mason notes that *"[T]heoretical figures show that the cell radius using 800MHz can be around 5% greater than that using the 900MHz band in rural areas. This translates into around a 10% greater coverage area for a single site. However, in practice it is our experience that operators consider the cell radii achievable across the two bands to be roughly equal"*[121].

281. In Table 27 below, we summarise estimates of relative cell area by frequency band, using 1800MHz as the base. We note that only one source of evidence from Table 26 above (Analysys Mason quoting external source (from Hi3G's confidential response to the January 2012 Consultation)) has also presented

[118] Hi3G Confidential Response to Ofcom's *Second consultation on assessment of future mobile competition and proposals for the award of 800MHz and 2.6GHz spectrum and relative issues*, January 2012 (January 2012 Consultation), Annex I.

[119] ibid

[120] PA Consulting, 2010, *Study on comparability of frequency bands in different business models*, prepared for MinisterieMinisterir van Economische Zaken (MEZ), 2010,

[121] Hi3G Confidential Response to January 2012 Consultation, Annex I.

information on relative cell area (which is linked to relative cell radii by the fact that a cell with double the radius covers four times the area).

Table 27: Normalised relative cell area of different frequency bands

	800MHz	900MHz	1800MHz	2.1GHz	2.6GHz
Analysys Mason quoting external source (from Hi3G's confidential response to the January 2012 Consultation[122]) – varies across dense urban, urban, sub-urban and rural geotype	4.0	3.6	1.0	-	-
Typical site coverage area achieved by Finnish operator Elisa[123] – varies between urban and suburban geotypes	2.7-2.8	2.3-2.4	1.0	0.8	0.5

282. We note that there is less agreement across various sources on relative cell areas for different bands. Elisa's figures support the view that the 800MHz band and the 900MHz band are very similar in terms of their propagation characteristics. The cell area reached by 1800MHz is approximately 20% higher than 2.1GHz. Elisa also notes that while the typical coverage area of 900MHz is expected to be three times that of 2.1GHz (in the table above the coverage area of 900MHz relative to 2.1GHz is 3.5), the actual coverage area of 900MHz is between three to five times larger. This means that Hi3G's estimates of relative coverage are consistent with Elisa's practical experience.

283. PA Consulting in its work for the Dutch Ministry of Economic Affairs (MEZ) noted that while the cell radius for sub-1GHz spectrum is similar across geotypes, it varies significantly for supra-1GHz spectrum, which in turns results in a more pronounced discrepancy in coverage areas between sub- and supra-1GHz spectrum. PA consulting estimated that:

> *"The coverage area of a cell in a rural area using supra-1GHz spectrum is between 50-60% less than the coverage area of a cell using sub-1GHz spectrum*

[122] Hi3G Confidential Response to January 2012 Consultation, Annex I.

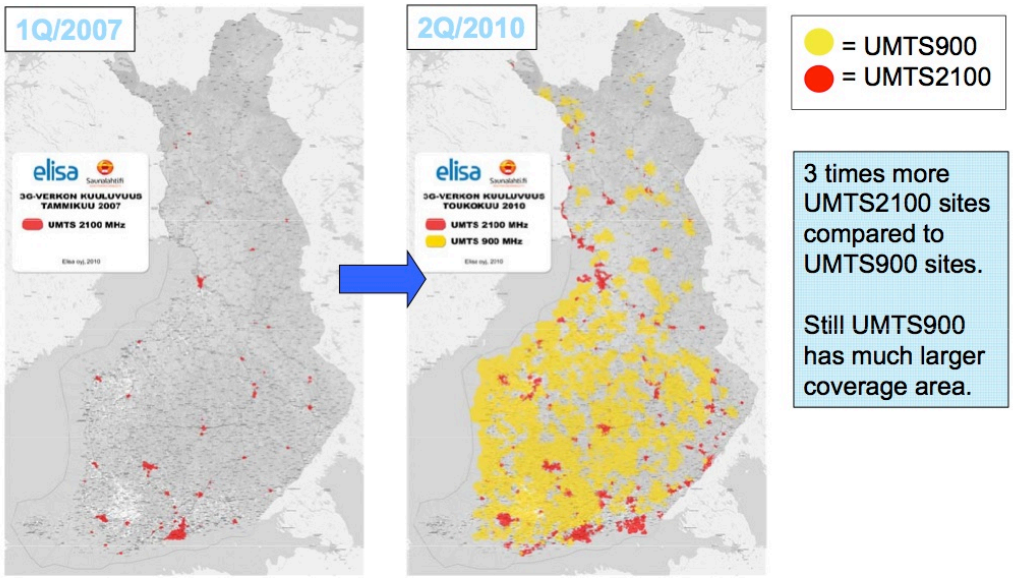
[123] *Developing a fully inclusive mobile broadband strategy: To remote and rural areas*, presentation by Eetu Prieur at Mobile Broadband World, London, 23 Sep 2009, slide 12.

The coverage area of a cell in an urban or suburban area using supra-1GHz spectrum is between 83-96% less than the coverage area of a cell using sub-1GHz spectrum." [124]

We note that PA consulting's estimates of relative coverage area of supra- versus sub- 1GHz spectrum is significant lower than those presented in Table 27.

284. The difference in propagation characteristics can mean substantial differences in coverage achieved using different bands. Figure 24 below shows the increase in 3G coverage within 3 years from the deployment of UMTS900 by Elisa compared to the situation when only 2.1GHz was used to provide 3G services.

Figure 24: Elisa 3G coverage between 2007-2010



Source: *"Coverage optimised mobile broadband solutions: UMTS900 with HSPA Evolution and LTE1800"*, presentation by Eetu Prieur at the LTE World Summit, Amsterdam, 18 May 2010

285. In its study for the MEZ, PA Consulting estimated the relative number of sites (against the case of 800MHz) required for a network to provide national mobile coverage in the Netherlands. This is presented below Figure 25. We note that PA Consulting has assumed that the building penetration signal loss in urban areas (20dB) is much larger than in rural areas (5dB). This may partly explain why PA Consulting considers that the disadvantage of supra 1GHz spectrum is less in rural areas than in suburban and urban ones.

[124] PA Consulting, 2010, *Study on comparability of frequency bands in different business models*, prepared for Ministerie van Economische Zaken (MEZ), page 22.page 22.

Figure 25: Relative number of base stations required to achieve national mobile coverage in the Netherlands

Multiples vs 800 MHz	800 MHz	900 MHz	1800 MHz	2100 MHz	2600 MHz
Urban	X 1.0	x 1.2	x 5.9	X 7.9	X 10.9
Suburban	X 1.0	x 1.1	x 14.7	X 19.7	X 27.4
Rural	X 1.0	x 1.1	x 1.9	X 2.2	x 2.4

Source: PA Consulting, 2010, *Study on comparability of frequency bands in different business models*, prepared for Ministerie van Economische Zaken (MEZ)

286. The UMTS Forum White Paper on Deployment of UMTS in the 900MHz band suggests that offering the same data services and UMTS coverage with 900MHz spectrum requires 60% fewer sites than using 2.1GHz.[125] This is consistent with, Vilicom's analysis for ComReg, which estimates that using 900MHz rather than 1800MHz reduces the number of sites by 47%, and that using 900MHz rather than 2.1GHz leads to a reduction by 57%. By contrast, moving from 2.1GHz to and 1800MHz reduces the number of sites needed by only 19%. Both the UMTS Forum White Paper and Vilicom suggest a much lower site count reduction (when using sub-1GHz spectrum compared to supra-1GHz spectrum) than that suggested by PA Consulting.

287. As part its competition assessment of the UK mobile market in relation to the UK 4G auction proposals, Ofcom performed some technical analysis of the downlink performance of LTE macrocell networks using paired spectrum from the 800MHz, 1800MHz and 2.6GHz bands. Annex 7 of the January 2012 Consultation Document[126] presents the key results of this analysis. In this technical analysis, network coverage for different endowments of spectrum across a range of frequency bands were modelled for two simulation areas – West London and Cambridge.

288. Ofcom found that for a network with a small number of sites (2000 nationally), 2x10MHz of 800MHz achieved a coverage of 92% of locations in West London for the provision of a 1Mbps service, but the same amount of 1800MHz spectrum covered only 72% locations, and 2.6GHz only 59%.[127] This difference in coverage reach between bands however diminishes with an

[125] UMTS Forum, 2006, *Deployment of UMTS in 900MHz band*, White Paper, Section 2.

[126] Ofcom, 2012, *Second consultation on assessment of future mobile competition and proposals for the award of 800MHz and 2.6GHz spectrum and relative issues, Annex 7*, January 2012

[127] Ofcom models these results for two scenarios - "min var" and "max var". Ofcom notes in paragraph A7.4 of its January 2012 Consultation document that "*[T]o reflect the major areas of uncertainty we have chosen to model a range of values for key parameters. To illustrate this range we have chosen to group the parameter values into two cases: those that tend, in most circumstances, to minimise the relative performance variation between frequencies ('Min var') and those that tend, in most circumstances, to maximise the relative performance variation ('Max var').*" Figures presented in paragraph 288 is the coverage in Ofcom's "min var" scenario and assumes a network loading of 85%.

increasing number of sites. At 20,000 sites nationally for instance, 2x10MHz of 800MHz reached 99% of locations while 1800MHz reached 95% and 2.6GHz reached 88% of locations.[128]

289. In summary, the technical studies we have reviewed differ in their views on the reduction in the number of sites required to achieve a given level of coverage. In particular, the PA Consulting work for MEZ would seem to produce rather different estimates of the impact on cell site requirements from much of the other technical work. Some of the differences across the technical studies may be explained by differences in network topography, available capacity, services modelled and other modelling specifics. However, despite the differences in the estimated magnitude of the effect, it is clear that sub 1GHz spectrum is better for achieving coverage than spectrum above 1GHz. More specifically:

- using sub-1GHz spectrum lowers the number of sites required for roll out relative to supra-1GHz spectrum;
- 800MHz and 900MHz are quite similar in terms of their propagation characteristics; and
- 1800MHz and 2.1GHz are also quite similar in terms of their propagation characteristics thought the gap here is slightly wider than between 800MHz and 900MHz.
- 1800MHz has significantly better propagation characteristics than 2.6GHz.

290. In Annex 7 of the January 2012 Consultation, Ofcom notes on examining the differences in network performance of a LTE network operated at 900MHz rather 800MHz, and 2.1GHz relative to 1800MHz, Ofcom found that these differences were small.[129] This is consistent with our conclusions above.

C.1.2 Band difference impact on network cost

291. Reduction in number of sites required to provide coverage will decrease network cost, both in terms of the capital expenditure required for network roll out as well as the operating expenditure associated with the day to day running of the network. Elisa estimates that total network costs (capex plus opex) of providing UMTS coverage in Finland using 900MHz is 50%-70% of that using 2.1GHz.[130]

292. In a study for the GSM Association on the economics of 3G-network roll out at different frequency bands, Ovum finds that the total network cost of a

[128] See Figures 5 through to 8 in Annex of January 2012 Consultation Document.

[129] Annex 7, paragraph A7.113, Ofcom, 2012, *Second consultation on assessment of future mobile competition and proposals for the award of 800MHz and 2.6GHz spectrum and relative issues*, January 2012

[130] *Developing a fully inclusive mobile broadband strategy: To remote and rural areas*, presentation by Eetu Prieur at Mobile Broadband World, London, 23 Sep 2009

UMTS900 network is between 60%-90% of UMTS2100, depending on geography. Africa and the Middle East represent the lower end of that range, and Western Europe (under a medium demand scenario) the upper end.[131]

293. Optus reports that in Australia the investment required to roll out UMTS with 900MHz is at most 63% of that using 2.1GHz.[132] This is consistent with the estimate by Vilicom that the deployment cost of UMTS900 would be 66% that of UMTS2100, and 74% that of UMTS1800.

294. Somewhat out of line with these estimates, PA Consulting's analysis for the MEZ suggests that using 800MHz rather than 900MHz spectrum reduces costs by 17%, and using 800MHz instead of 1800MHz produces a 88% reduction in costs. Table 28 below summarises the relative network deployment cost between different frequency bands from the studies referenced above. PA Consulting figures are out of line with the remaining estimates. This may be explain amongst other factors by the large differences in PA Consulting's estimates of number of sites required per band relative to other sources of evidence discussed above.

Table 28: Relative network deployment cost between frequency bands

Relative cost of using (a) rather than (b)		(b)			
		900MHz	1800MHz	2.1GHz	2.6GHz
(a)	800MHz	83%*	12%*	9%*	6.5%*
	900MHz	-	14%*	63%***	-
			74%**	66%**	
	1800MHz	-	-	88%**	55%*

* PA Consulting for MEZ, ** Vilicom for ComReg, *** Optus Australia UMTS Case Study

295. Overall, we conclude from the evidence presented in this section that:

- 800MHz and 900MHz should have comparable technical value to an operator;
- 1800MHz and 2.1GHz should have comparable technical merit though 1800MHz has slightly better propagation characteristics than 2.1GHz. 1800MHz in turn should be worth and a good deal more than 2.6GHz; and
- Sub-1GHz spectrum should be worth substantially more than 1800MHz.

[131] Ovum Consulting, 2007, *Market Study for UMTS900*, prepared for GSMA.

[132] Optus, *UMTS900 – A Case Study*, June 2009.

C.2 Impact of band differences on spectrum value – operators' views

Value of 800MHz versus 900MHz

296. While there is general consensus within industry on the comparable propagation characteristics of 800MHz and 900MHz spectrum as presented above, there is little consensus amongst the mobile operators about the relative market value of 800MHz and 900MHz spectrum. The main differences seem to result from different views of equipment availability, interference, channel size and fragmentation.

297. There are two differing views here that we have summarised based on O2's, Vodafone's, EE's and Hi3G's confidential responses to the UK multiband auction consultations:

- The first view put forth by O2 and Vodafone is that 900MHz is worth less than 800MHz because HSPA is not a good substitute for LTE and LTE deployment in the 900MHz band is difficult and relatively less attractive. Specifically, Vodafone notes that *"HSPA cannot match the performance of LTE in terms of latency, speed, spectral efficiency, prioritisation and capacity."*[133] The 900MHz band suffers from lack of available spectrum due to existing GSM use and band fragmentation. There is insufficient spectrum for a 2x10MHz channel, which is the only LTE carrier size available in the 900MHz band at present. Clearing the band for LTE use will also be timely and costly. In any case, availability of LTE network equipment and devices in the 900MHz band is poor compared to 800MHz, and there are potential interference issues from neighbouring uses such as Network Rail.[134]

- The opposite view put forth by EE and Hi3G is that 900MHz spectrum is worth more than 800MHz spectrum because HSPA+ can provide comparable performance to LTE in the short to medium term. There is an existing 3G customer base giving a first-mover advantage to HSPA+. Equipment for mobile broadband is immediately available via HSPA+. Device availability is better in the 900MHz band than 800MHz band in the short term. HSPA900 capable handsets already exist and the number of HSPA900 devices available is much higher than the case of LTE800. There are less interference issues in the 900MHz band as it is not adjacent to TV broadcasters as is the 800MHz band and in the long term the LTE900 ecosystem should develop.[135]

[133] Vodafone, response to the January 2012 Consultation, page 3.

[134] See O2 response to the January 2012 Consultation, paragraph 312; Vodafone response to the March 2011 Consultation, paragraphs 2 (v), 52, 55, and 157; Vodafone response to the January 2012 Consultation; paragraph 77.

[135] EE response to the March 2011 Consultation, Section 6.2. Hi3G confidential response to the January 2012 Consultation, Annex I.

298. Hi3G was the only operator to quantify the value difference between 800MHz and 900MHz spectrum. In Hi3G's confidential response to the January 2012 Consultation it presented a study by Analysys Mason monetising the incremental value of 900MHz over 800MHz spectrum. Analysys Mason argues that 900MHz spectrum would allow competitive rural coverage and good in-building penetration and thus increase the operator's market share by one percentage point. Early device availability in the 900MHz band would allow holders of 900MHz a first mover advantage to serve the existing customer base and achieve this one percentage point increase in market share more quickly than would be the case with LTE800. This would result in incremental cash flows of £50m-£70m per annum over five years for the 900MHz operator, or an NPV of £350m over a ten-year period. This is equivalent to an incremental value of £0.27 per MHz per capita over 800MHz (assuming a spectrum endowment of 2x10MHz of 900MHz spectrum is needed to realise these benefits).[136]

299. On this debate, Ofcom notes in Annex 6 of its January 2012 Consultation Document that *"[I]t is unclear the extent to which consumers are likely to value the features that LTE can deliver over and above HSPA…It is possible that any competitive advantage associated with holding spectrum suitable for early deployment of LTE could last for some years. However, it may be that the features associated with LTE are only valued by a small group of consumers, particularly in the early stages of LTE deployment. Indeed, for a period, there could also be advantages of HSPA over LTE because of a larger range or stock of compatible devices… However, in the longer term it may be more important to be able to offer LTE services, as the advantages over HSPA are likely to become more pronounced".*[137]

300. Overall, we consider that there is little agreement amongst the mobile operators as to the relative value of 800MHz and 900MHz spectrum, particularly in the short to medium term.

301. Kerans et al (2011) model the impact of physical spectrum attributes on spectrum value based on infrastructure cost savings across frequency bands. The study found that the relationship between spectrum value and frequency band follows an inverse exponential function, as shown in Figure 26 below. The costs of network deployment are minimised at 850MHz, and lower frequencies have a similar value because of limitations of network technology that do not vary with frequency. The paper notes that *"[T]he curve fits well with the Swedish 2.5GHz auction results (for FDD spectrum) as well a historic spectrum value for 1.8GHz (1998 auction) and 3.4GHz (2000 auction)* (in Australia). *The curve does not fit well with the* (Australian)*1.8GHz and 2GHz auction results of 2000 which indicates that the price paid for these bands was unjustifiably high. This assertion is supported by one of the companies that 'won' a large proportion*

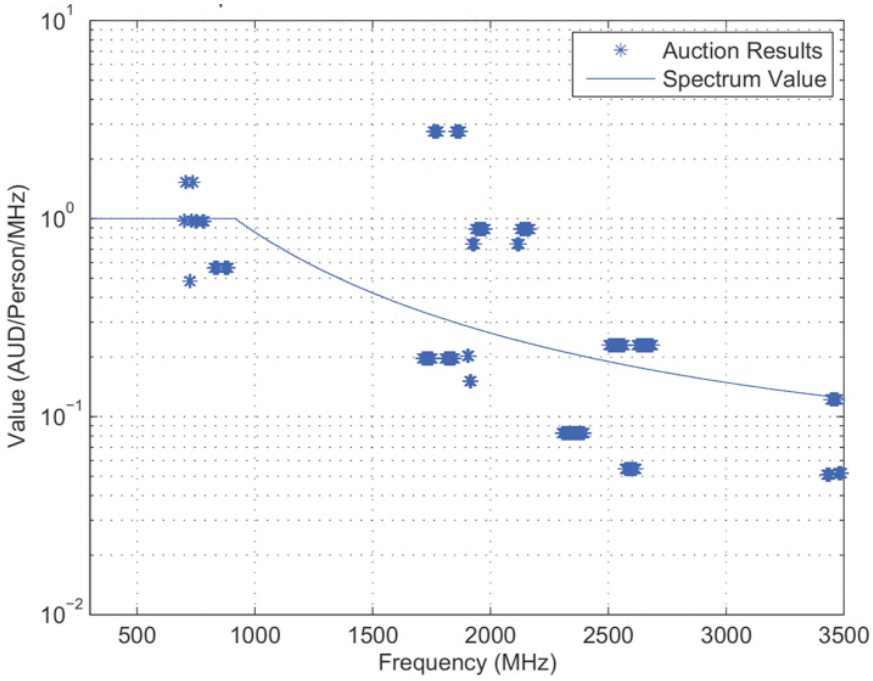
[136] Hi3G confidential response to the January 2012 consultation, Annex I.

[137] Annex 6, paragraph A3.220 of Ofcom, 2012, *Second consultation on assessment of future mobile competition and proposals for the award of 800MHz and 2.6GHz spectrum and relative issues,* January 2012.

of 1.8GHz going bankrupt shortly after the auction with the spectrum being unused since 2000. "[138]

302. We note that while the 1.8GHz price in the 2000 Australian auction does exceed the upper bound of our estimated valuation range summarised in Section 2.2.7, this auction has not been identified as an outlier by any of our three methods described in Section 2.1.3. Overall, the study by Kerans et al would suggest that 800MHz is worth about 10% more than 900MHz, and 900MHz spectrum is worth about two and a half times the value of 1800MHz. However, we note that this study draws from a narrow sample of auctions in Australia, US and Sweden, and is some what dismissive of some observations without strong reason. One should therefore be careful when using these findings, and the authors themselves note that *"the paper does not suggest that this method should be used alone to determine how spectrum is priced."*[139]

Figure 26: Spectrum value based on technical characteristics



Source: Kerans et al (2011) Figure 5

Other relative band values

303. Vodafone commented in its response to the January 2012 Consultation Response that the ratio of eligibility points between bands in the auction should roughly reflect the ratio of market values. Vodafone suggested that the eligibility point for the 2x45MHz 1800MHz lot could be reduced to 45 points

[138] Section V of Kerans, A, Vo, D., Conder, P., Krusevac, S. (2011), *Pricing of Spectrum Based on Physical Criteria*, Proceedings of IEEE DySPAN (2011), pp. 223–230.

[139] Kerans et al, op cit

from the 60 points proposed in the consultation document. This would yield a ratio of eligibility points for 800MHz to 1800MHz to 2.6GHz ratio of 6:3:1, suggesting that the market value of 800MHz is roughly twice that of 1800MHz, and that 1800MHz is worth three times as much as 2.6GHz.

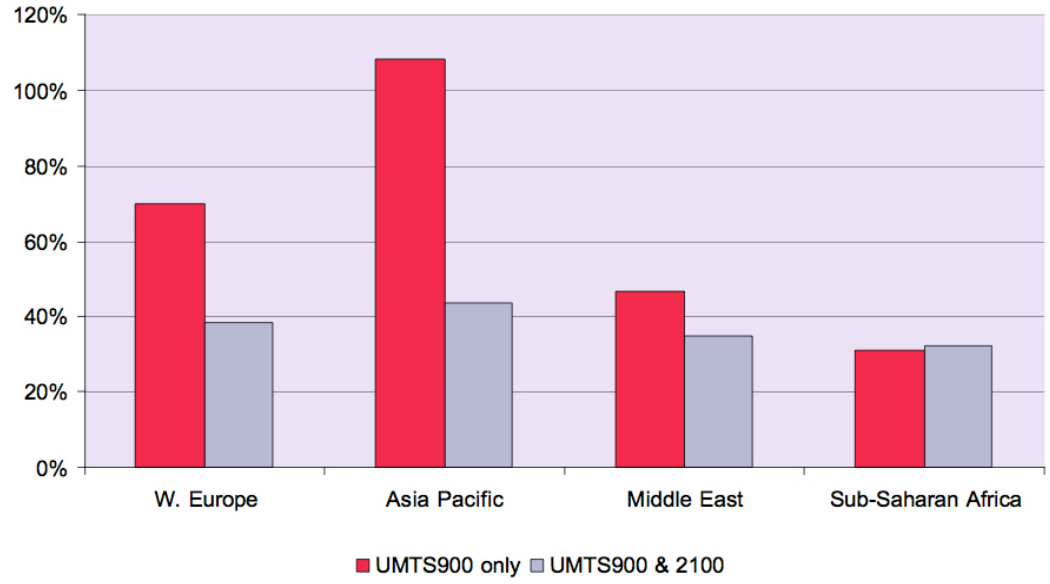
C.3 Insights from business modelling

Ovum NPV analysis for GSMA

304. Ovum in a study for the GSMA looked at the NPV improvements of using 900MHz for UMTS relative to 2.1GHz. Specifically, Ovum calculated the net present value (NPV) improvements that would result from the use of 900MHz instead of (rather than in addition to) 2.1GHz for UMTS. This analysis was done for different geographical regions including, Western Europe, Asia Pacific, Middle East and Africa. In its basic analysis (see Figure 27 below), Ovum found that the NPV improvements of UMTS900 over UMTS2100 from reduced capex and opex ranged from roughly 10% in Western Europe to almost 60% in Africa.

305. Ovum extended its analysis to investigate the NPV improvements that would result if the capex savings from using 900MHz were reinvested by the operator to extend geographical coverage and attract new subscribers. In this case, which Ovum considered to be more realistic in terms of modelling real world behaviour, Western Europe and Asia Pacific would experience the highest NPV improvements due to the larger potential addressable market in these regions. Here Ovum estimated NPV improvements from UMTS900 relative to UMTS2100 of roughly 70% in Western Europe.

Figure 27: NPV improvement over UMTS2100 in medium demand scenario - basic analysis



Source: Ovum, UMTS 900 Market Study, prepared for the GSMA

Analysys Mason network cost saving model of 700MHz for Ofcom

306. Analysys Mason together with Aegis Systems in a study for Ofcom in 2013 estimated the opportunity cost of using 700MHz (614-791MHz) spectrum for

the transmission of Digital Terrestrial Television (DTT).[140] They calculated the value of 700MHz spectrum to a variety of uses including the value to mobile operators. Specifically for mobile operators, they modelled the technical value of 700MHz spectrum to a generic operator. This is the cost savings the generic operator would enjoy from the reduction in roll out cost as a result of access to 700MHz spectrum. Commercial value of spectrum associated with increased ARPU or market share was not modelled.

307. A base case[141] of the generic operator with the following holding of spectrum was modelled:

- 2x10MHz of 800MHz;
- 2x5MHz of 900MHz;
- 2x15MHz of 1800MHz, 2.1GHz and 2.6GHz (FDD)
- 40MHz of 2.3GHz
- 50MHz of 2.6MHz (TDD)

308. The value of 2x5MHz, 2x10MHz and 2x15MHz of 700MHz licence running from 2020 to 2034 to the generic operator in the base case was estimated to be £378m, £539m and £606m in 2015 prices.[142] This translates into per MHz per capita prices of £0.60, £0.43 and £0.32 respectively.[143]

[140] Analysys Mason and Aegis Systems, 2013, *Opportunity cost of the spectrum used by digital terrestrial TV and digital audio broadcasting*, Report for Ofcom, available at: http://stakeholders.ofcom.org.uk/binaries/consultations/aip13/annexes/report.pdf (accessed 02052013)

[141] The study also modeled a range of alternative scenarios of spectrum holdings for the generic operator.

[142] In its analysis, Analysys Mason used a discount rate of 8.86% which is identical to the nominal WACC figure we use in our analysis in this report as well as that in our Spectrum Value Report.

[143] Calculated using a UK population figure of 63 million.

Annex D Prices using alternative WACC

In this Annex, we present per MHz per population prices for all auction benchmarks, spectrum trades and renewal fees using a real post-tax WACC rate of 4.10% . Relative band values derived from using this rate are also presented.

D.1 Auction benchmarks

D.1.1 900MHz

Table 29: 900MHz auctions

Auction	WACC 4.10%		WACC 8.86%	
	Licence Price	Minimum Price	Licence Price	Minimum Price
Hong Kong China (2011)	£2.449	£0.093	£2.272	£0.081
Hungary (2012)	£1.464	£0.239	£1.361	£0.222
Greece (2011)	£0.498	£0.497	£0.463	£0.462
Spain (2011)	£0.403	£0.403	£0.391	£0.391
Spain (2011)	£0.386	£0.386	£0.376	£0.376
Romania (2012)	£0.395	£0.395	£0.367	£0.367
Portugal (2011)	£0.381	£0.381	£0.354	£0.354
Norway (2001)	£0.327	£0.301	£0.238	£0.215
Austria (2002)	£0.135	£0.135	£0.129	£0.129
Austria (2008)	£0.059	£0.007	£0.049	£0.006
Denmark (2010)	£0.038	£0.038	£0.031	£0.031
Singapore (2008)	£0.039	£0.039	£0.029	£0.029
New Zealand (2002)	£0.020	£0.019	£0.020	£0.019
Austria (2004)	£0.008	£0.007	£0.007	£0.006
Switzerland (2012)	N/A	£0.150	N/A	£0.139
Ireland (2012)	N/A	£0.444	N/A	£0.352
Netherlands (2012)	N/A	£0.161	N/A	£0.153

D.1.2 800MHz

Table 30: 800MHz auctions

Auction	WACC 4.10%		WACC 8.86%	
	Licence Price	Minimum Price	Licence Price	Minimum Price
Italy (2011)	£0.764	£0.547	£0.743	£0.532
Germany (2010)	£0.793	£0.003	£0.737	£0.003
Korea Rep. (2011)	£0.744	£0.744	£0.637	£0.637
Portugal (2011)	£0.572	£0.572	£0.531	£0.531
Spain (2011)	£0.498	£0.389	£0.484	£0.378
Netherlands(2012)	£0.443	£0.194	£0.424	£0.185
Sweden (2011)	£0.249	£0.109	£0.265	£0.116
Denmark (2012)	£0.160	£0.075	£0.138	£0.062
Australia (1998)	£0.147	£0.045	£0.137	£0.042
Brazil (2007)	£0.133	£0.051	£0.123	£0.047
Australia (1998)	£0.131	£0.131	£0.122	£0.122
Nigeria (2007)	£0.161	£0.161	£0.117	£0.117
Australia (1999)	£0.014	£0.014	£0.013	£0.013
Ireland (2012)	N/A	£0.444	N/A	£0.352
Romania (2012)	N/A	£0.345	N/A	£0.321
Switzerland (2012)	N/A	£0.143	N/A	£0.135

Table 31: 800MHz awards

Award	WACC 4.10%		WACC 8.86%	
	Licence Price	Minimum Price	Licence Price	Minimum Price
Croatia (2012)	£0.973	£0.973	£0.754	£0.754
France (2011)	£0.542	£0.370	£0.542	£0.370
Macao China (2006)	£0.001	£0.001	£0.001	£0.001

D.1.3 700MHz

Table 32: 700MHz auctions

Auction	WACC 4.10%		WACC 8.86%	
	Licence Price	Minimum Price	Licence Price	Minimum Price
United States (2008)	£1.211	£0.061	£1.036	£0.052
United States (2011)	£0.633	£0.056	£0.541	£0.048
United States (2005)	£0.185	£0.023	£0.158	£0.019
United States (2002)	£0.061	£0.030	£0.054	£0.027
United States (2003)	£0.044	£0.012	£0.039	£0.011
Australia (2013)	N/A	£0.679	N/A	£0.631

D.1.4 1800MHz

Table 33: Sample summary statistics using WACC of 4.10%

Sample	Observations	Mean	Standard Deviation	95% confidence interval
1995-2012 excluding outliers	39	0.352	0.390	0.229 - 0.474
1995-2012 excluding outliers, above reserve	29	0.421	0.419	0.269 - 0.573

Table 34: Sample summary statistics using WACC of 8.86%

Sample	Observations	Mean	Standard Deviation	95% confidence interval
1995-2012 excluding outliers	39	0.316	0.339	0.209 - 0.422
1995-2012 excluding outliers, above reserve	29	0.373	0.361	0.242 - 0.505

Table 35: 1800MHz auctions 2010 - 2012

Auction	WACC 4.10%		WACC 8.86%	
	Licence Price	Minimum Price	Licence Price	Minimum Price

Korea Rep. (2011)	£1.419	£0.635	£1.214	£0.543
Singapore (2011)	£0.758	£0.040	£0.600	£0.030
Italy (2011)	£0.246	£0.241	£0.239	£0.235
India (2012)	£0.284	£0.284	£0.227	£0.227
Greece (2011)	£0.219	£0.219	£0.204	£0.203
Sweden (2011)	£0.145	£0.007	£0.154	£0.008
Mexico (2010)	£0.108	£0.008	£0.108	£0.008
Portugal (2011)	£0.050	£0.050	£0.046	£0.046
Germany (2010)	£0.028	£0.003	£0.026	£0.003
Denmark (2010)	£0.016	£0.016	£0.013	£0.013

Table 36: 1800MHz auctions 2006 – 2009

Auction	**WACC 4.10%**		**WACC 8.86%**	
	Licence Price	Minimum Price	Licence Price	Minimum Price
Bulgaria (2008)	£0.558	£0.558	£0.558	£0.558
Hong Kong China (2009)	£0.460	£0.326	£0.342	£0.223
Georgia (2006)	£0.225	£0.098	£0.333	£0.145
United States (2007)	£0.367	£0.073	£0.314	£0.063
United States (2008)	£0.264	£0.031	£0.226	£0.027
Brazil (2007)	£0.066	£0.045	£0.062	£0.041
Singapore (2009)	£0.045	£0.039	£0.034	£0.029
Singapore (2008)	£0.039	£0.039	£0.029	£0.029
Brazil (2007)	£0.011	£0.011	£0.010	£0.010

Table 37: 1800MHz auctions 2001 – 2005

Auction	**WACC 4.10%**		**WACC 8.86%**	
	Licence Price	Minimum Price	Licence Price	Minimum Price
United States (2001)	£3.144	£0.077	£2.690	£0.066

United States (2005)	£0.806	£0.315	£0.690	£0.270
Canada (2001)	£0.533	£0.111	£0.456	£0.095
Israel (2001)	£0.375	£0.375	£0.375	£0.375
Austria (2001)	£0.229	£0.229	£0.222	£0.222
Greece (2001)	£0.222	£0.222	£0.222	£0.222
Norway (2001)	£0.150	£0.150	£0.108	£0.108
New Zealand (2001)	£0.096	£0.000	£0.089	£0.000
Austria (2004)	£0.007	£0.007	£0.006	£0.006
Singapore (2001)	£0.006	£0.006	£0.005	£0.005

Table 38: 1800MHz auctions 1995 – 2000

Auction	WACC 4.10%		WACC 8.86%	
	Licence Price	Minimum Price	Licence Price	Minimum Price
United States (1996)	£3.472	£0.000	£2.970	£0.000
United States (1996)	£1.736	£0.000	£1.485	£0.000
Australia (2000)	£1.070	£0.097	£0.994	£0.090
Austria (1997)	£0.690	£0.000	£0.690	£0.000
United States (1995)	£0.760	£0.000	£0.650	£0.000
Austria (1999)	£0.427	£0.000	£0.427	£0.000
United States (1997)	£0.482	£0.000	£0.413	£0.000
Netherlands (1998)	£0.310	£0.000	£0.288	£0.000
Germany (1999)	£0.202	£0.005	£0.172	£0.004
United States (1999)	£0.148	£0.057	£0.127	£0.048
Australia (1998)	£0.087	£0.045	£0.077	£0.042
Australia (1998)	£0.077	£0.073	£0.072	£0.068

D.1.5 2.1GHz

Table 39: 2.1GHz summary statistics using WACC of 4.10%

Sample	Observations	Mean	Standard Deviation	95% confidence interval
2000-2012 excluding outliers	34	0.440	0.403	0.304 - 0.575
2000-2012 excluding outliers, above reserve	26	0.455	0.449	0.282 - 0.628

Table 40: 2.1GHz summary statistics using WACC of 8.86%

Sample	Observations	Mean	Standard Deviation	95% confidence interval
2000-2012 excluding outliers	34	0.405	0.391	0.273 - 0.536
2000-2012 excluding outliers, above reserve	26	0.420	0.437	0.252 - 0.588

D.1.6 2.6GHz

Table 41: 2.6GHz auctions

Auction	WACC 4.10%		WACC 8.86%	
	Minimum Price	Licence Price	Minimum Price	Licence Price
Hong Kong China (2009)	£0.416	£0.128	£0.384	£0.117
Denmark (2010)	£0.151	£0.015	£0.147	£0.011
Sweden (2008)	£0.153	£0.003	£0.142	£0.003
Belgium (2011)	£0.072	£0.072	£0.061	£0.061
Italy (2011)	£0.056	£0.047	£0.054	£0.046
Spain (2011)	£0.049	£0.011	£0.048	£0.011
Portugal (2011)	£0.038	£0.038	£0.035	£0.035
Austria (2010)	£0.028	£0.005	£0.027	£0.004

Germany (2010)	£0.024	£0.003	£0.023	£0.003
Norway (2007)	£0.020	£0.002	£0.019	£0.002
Australia (2013)	£0.015	£0.015	£0.014	£0.014
Netherlands (2010)	£0.006	£0.005	£0.004	£0.004
Finland (2009)	£0.002	£0.002	£0.001	£0.001
Switzerland (2012)	N/A	£0.051	N/A	£0.050
Romania (2012)	N/A	£0.039	N/A	£0.037

Table 42: 2.6GHz awards

Award	WACC 4.10%		WACC 8.86%	
	Licence Price	Minimum Price	Licence Price	Minimum Price
France (2012)	£0.082	£0.062	£0.082	£0.062

D.2 CCA cross checks

Table 43: Switzerland

		Orange	Sunrise	Swisscom
	800MHz (16 years)	20	20	20
	900MHz (15 years)	10	30	30
	1800MHz (15.4 years)	50	40	60
	2.1GHz (13.5 years)	40	20	60
	2.6GHz (18 years)	40	50	40
	2.6GHz TDD (18 years)	0	0	45
WACC 4.1%	Auction package price (£millions)	71	222	166
	Package price implied by lower bound estimates (£millions)	250	251	368
	Package price implied by upper bound estimates (£millions)	483	458	667
WACC 8.86%	Auction package price (£millions)	71	222	166
	Package price implied by lower bound estimates (£millions)	248	250	365
	Package price implied by upper bound estimates (£millions)	480	454	664

Table 44: Romania

	Cosmote	Orange	Vodafone	RCS&RDS

	800MHz (15 years)	10	20	20	0
	900MHz (1.25 years)	0	25	25	0
	900MHz (15 years)	20	20	20	10
	1800MHz (1.25 years)	0	30	30	0
	1800MHz (15 years)	50	40	60	0
	2.6GHz (15 years)	20	40	0	0
	2.6GHz TDD (15 years)	0	0	15	0
WACC 4.1%	Auction package price (£millions)	311	392	395	69
	Package price implied by lower bound estimates (£millions)	429	514	565	66
	Package price implied by upper bound estimates (£millions)	777	935	1,000	87
WACC 8.86%	Auction package price (£millions)	311	392	395	69
	Package price implied by lower bound estimates (£millions)	427	525	572	66
	Package price implied by upper bound estimates (£millions)	764	944	995	87

Table 45: Ireland

		H3G	Meteor	Telefonica	Vodafone
	800MHz (2.4 years)	0	20	20	20
	800MHz (15 years)	0	20	20	20
	900MHz (2.4 years)	10	10	20	20
	900MHz (15 years)	10	20	20	20
	1800MHz (2.4 years)	20	20	0	30
	1800MHz (15 years)	40	30	30	50
WACC 4.1%	Auction package price (£millions)	76	182	166	208
	Package price implied by lower bound estimates (£millions)	53	96	96	117
	Package price implied by upper bound estimates (£millions)	96	165	163	206
WACC 8.86%	Auction package price (£millions)	67	166	150	190
	Package price implied by lower bound estimates (£millions)	54	99	99	121
	Package price implied by upper bound estimates (£millions)	96	168	165	209

Table 46: Netherlands

		KPN	T-Mobile	Vodafone	Tele2
	800MHz (17 years)	20	0	20	20

	900MHz (17 years)	20	30	20	0
	1800MHz (17 years)	40	60	40	0
	1900MHz TDD (4 years)	0	14.6	0	0
	2.1GHz (4 years)	10	0	10	0
	2.6GHz TDD 17 years)	30	25	0	0
WACC 4.1%	Auction package price (£millions)	1,117	754	1,140	133
	Package price implied by lower bound estimates (£millions)	403	383	398	133
	Package price implied by upper bound estimates (£millions)	701	654	697	238
WACC 8.86%	Auction package price (£millions)	1,116	753	1,139	133
	Package price implied by lower bound estimates (£millions)	394	367	389	133
	Package price implied by upper bound estimates (£millions)	677	617	672	232

Table 47: United Kingdom

		EE	H3G	O2	Vodafone	Niche
	800MHz (20 years)	10	10	20	20	0
	2.6GHz (20 years)	70	0	0	40	30
	2.6GHz TDD (20 years)	0	0	0	25	20
WACC 4.1%	Auction package price (£millions)	619	255	610	863	202
	Package price implied by lower bound estimates (£millions)	498	277	555	681	95
	Package price implied by upper bound estimates (£millions)	1,160	498	996	1,375	284
WACC 8.86%	Auction package price (£millions)	619	255	610	863	202
	Package price implied by lower bound estimates (£millions)	485	265	530	656	95
	Package price implied by upper bound estimates (£millions)	1,129	467	933	1,312	284

Table 48: Australia

		Optus Mobile	Telstra	TPG Internet
	700MHz (15 years)	20	40	0
	2.6GHz (15 years)	40	80	20
WACC 4.1%	Auction package price (£millions)	259	518	5
	Package price implied by lower bound estimates (£millions)	197	394	18
	Package price implied by upper bound estimates (£millions)	398	796	55

WACC 8.86%	Auction package price (£millions)	259	518	5
	Package price implied by lower bound estimates (£millions)	204	408	20
	Package price implied by upper bound estimates (£millions)	408	816	59

D.3 Relative band values

Table 49: Relativities implied within auctions

Auction	Band	WACC 4.10%	WACC 8.86%
Hong Kong (2011)	850MHz/900MHz	0.8	0.8
United States (2008)	1800MHz/2.1GHz	3.3	3.0

Table 50: Relativities implied within countries

Country	Band	WACC 4.10%	WACC 8.86%
Netherlands (2012/1998)	800MHz/1800MHz	1.4	1.5
Netherlands (1998/2000)	1800MHz/2.1GHz	0.2	0.2
Canada (2001/2008)	1800MHz/2.1GHz	0.5	0.5
Australia (2000/2001)	1800MHz/2.1GHz	1.4	1.4
Hong Kong (2011/2009)	900MHz/1800MHz	5.3	6.7
Hong Kong (2011/2009)	900MHz/2.6GHz	5.9	5.9
Hong Kong (2009/2009)	1800MHz/2.6GHz	1.1	0.9
United States (2008-2011/2005-2008)	700MHz/1900MHz	1.9	1.9
United States (2005-2008/2006-2008)	1900MHz/2.1GHz	3.7	3.4

D.4 Renewal fees

Table 51: Renewal fees

Country	Band	WACC 4.10%	WACC 8.86%
Australia (2011)	800MHz/900MHz	£0.67	£0.63
Australia (2011)	1800MHz	£0.13	£0.12

Belgium (2010)	800MHz/900MHz	£0.65	£0.46
Belgium (2010)	1800MHz	£0.33	£0.23
Belgium (2010)	2.1GHz	£0.26	£0.19
Belgium (2010)	2.6GHz	£0.04	£0.02
Ireland (2011)	800MHz/900MHz	£0.47	£0.33
Netherlands (2007)	800MHz/900MHz	£0.43	£0.32
Canada (2003)	800MHz/900MHz	£0.34	£0.25
Canada (2003)	1800MHz	£0.34	£0.25
New Zealand (2007)	800MHz/900MHz	£0.23	£0.23
France (2008)	800MHz/900MHz	£0.10	£0.07
France (2008)	1800MHz	£0.05	£0.04

D.5 Spectrum trades

Table 52: Spectrum trades

Trade	Band	WACC 4.10%	WACC 8.86%
US - Qualcomm/AT&T (2010)	700MHz	£1.29	£1.10
US - Aloha/AT&T (2007)	700MHz	£1.35	£1.15
US - Verizon/Grain (2013)	700MHz	£1.58	£1.35
US - Verizon/Leap (2012)	700MHz	£1.87	£1.60
US - Verizon/AT&T (2013)	700MHz	£4.15	£3.55
US - Nextwave/T-Mobile-AtlanticWireless-ACS-MetroPCS (2008)	2.1GHz	£0.22	£0.21
US - Cox/Verizon (2012)	2.1GHz	£0.47	£0.43
US - Cable Cos/Verizon (2012)	2.1GHz	£0.57	£0.53
Canada - Shaw/Rogers (2013/2014)	2.1GHz	£1.40	£1.20