JANUARY 2017

ANNEX 17 DRIVERS OF THE INTRINSIC VALUE OF HIGH-FREQUENCY SPECTRUM

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Glossary

Term	Definition
ARPU	Average Revenue Per User
AWS	Advanced Wireless Services
BT	British Telecommunications plc
COFETEL	Comisión Federal de Telecomunicaciones (Regulator in Mexico)
EBITDA	Earnings Before Interest, Tax, Depreciation and Amortisation
EE	Everything Everywhere
FCC	Federal Communications Commission (Regulator in the USA)
FTI	FTI Consulting LLP
GHz	Gigahertz frequency
MHz	Megahertz frequency
MHz pop	Megahertz spectrum per inhabitant in a country
NRA	National Regulatory Authorities
Ofcom	Office of Communications (Regulator in the UK)
PSSR	Public Sector Spectrum Release
Three	Hutchison 3G UK

1. Executive Summary

1.1 In connection with the upcoming 2.3 and 3.4 GHz spectrum auction in the UK (the PSSR auction[1]), FTI Consulting LLP (FTI) has been instructed by Hutchison 3G Limited (Three) to assess whether the size of an operator affects outcomes in auctions that include high-frequency 'capacity' spectrum. In addition to this, FTI has been instructed to consider if there is a material commercial value component to the value of high-frequency 'capacity' spectrum.

1.2 The value of spectrum may be divided into its 'strategic value'[2] and its 'intrinsic value'[3]. The intrinsic value may be further divided into (i) 'technical value' which reflects the network cost saving of holding additional spectrum compared to not holding it, and (ii) 'commercial value' which reflects the additional revenue from improved services, which would not be possible without the spectrum.

1.3 In this report we set out to determine if the value high-frequency 'capacity' spectrum increases as the size or market dominance of the operator increases. We also set out to find evidence of whether intrinsic value of high-frequency is driven by commercial value, technical value, or both.

1.4 Ofcom and Three may have different opinions regarding what drives value of high-frequency 'capacity' spectrum. We understand from Three that Ofcom has suggested that technical value is a key driver of high-frequency spectrum value. We also understand that Ofcom has suggested that operators with smaller spectrum holdings will tend to have a higher valuation for additional spectrum than those with a larger share of pre-auction spectrum. Specifically, Ofcom states that[4]:

1 PSSR is short for 'Public Sector Spectrum Release'

2 Strategic value, also referred to as strategic investment value, is the present value of additional expected profits earned from bids aimed at affecting the future structure of competition in mobile services by depriving one or more competitors of spectrum.

3 Intrinsic value is the present value of additional profits a bidder expects to earn when holding the spectrum versus not holding it, absent strategic considerations.

4 Para 4.166, Award of the 2.3 and 3.4 GHz spectrum bands. Competition issues and auction regulations, Ofcom, 21 November 2016

"In general, we would expect the value each MNO places on additional spectrum to reduce as it obtains more frequencies. This means that those operators with small spectrum holdings will tend to have higher values for additional spectrum than operators with high spectrum holdings. In turn, this may reduce the likelihood of this award resulting in a significantly more asymmetric distribution of spectrum because of differences in intrinsic value. We recognise, however, that there are many additional considerations that can affect the value of specific spectrum to different operators, such that this general tendency is not always the most important factor".

1.5 Whereas, Three suggests that there may also be a material commercial value component to high-frequency spectrum value and that the intrinsic value of high-frequency 'capacity' spectrum may be larger for larger operators.

1.6 Three requested that FTI tests the hypothesis that spectrum value increases with the size of an operator. Three also asked FTI to find supporting evidence that commercial value of spectrum is a driver of high-frequency capacity spectrum in addition to, or instead of, technical value.

1.7 To test this hypothesis, a dataset was compiled consisting of 323 observations[5] from 80 auctions since Q2 2008, including 223 participating operators across 52 countries[6]. As the value of the spectrum available in the PSSR auction may be more closely related to high frequency bands above 1400 MHz, the analysis was limited to those auctions that included a large proportion of high frequency spectrum.

1.8 [✂-FTI's conclusions][7].

[✂]

[8][✂][9][✂][10][✂].

[5] An observation refers to a participating operator in a given auction.

[6] When filtering out non-participating operators, auctions with no competition, and outliers, our dataset included 226 observations from 179 winning operators in 70 auctions. We collected price information from 165 winning operators in 63 auctions, historical spectrum holdings for 106 operators in 36 countries and estimated network utilisation figures for 63 winning operators in 34 auctions in 23 countries.

[7] [✂]

[8] [✂]

[10] [✂]

2. Introduction

Introduction

2.1 This report has been prepared by FTI Consulting LLP (FTI) for Hutchison 3G Limited (Three). FTI has been asked to advise on the value drivers for mobile spectrum and to test two hypotheses:

(1) Three's hypothesis that there is a strong connection between how large an operator is and how much high-frequency 'capacity' spectrum it is likely to win, especially in auctions where operators are not restricted by competitive remedies such as caps and set-asides; and

(2) The hypothesis that technical value, and not commercial, drives value of high-frequency spectrum.

2.2 Although this analysis is in the context of Three's response to Ofcom's consultation on the PSSR auction design[11], FTI does not provide any advice or recommendations on rules or policies relating to the PSSR auction itself, or any other auction.

Background

2.3 Three is the mobile network operator in the UK with the lowest market share. Three was the last network operator to enter the UK mobile market, entering in March 2003. [✂-Three's business case.][12][✂]

2.4 Three has stated to Ofcom that there is a strong connection between the strength of an operator prior to an auction and how much high-frequency spectrum they are likely to win. Three also states that the value of high-frequency capacity spectrum is, to some extent, driven by its commercial value component. Three has informed us that Ofcom has responded by arguing that the value of high-frequency spectrum does not necessarily increase with scale. We understand that Ofcom also argues that the value of high-frequency 'capacity' spectrum is mainly driven by its technical value component, which is related to avoided network costs.

[11] Ofcom, Award of the 2.3 and 3.4 GHz spectrum bands. Competition issues and auction regulations, consultation, 21st November 2016

[12] [✂]

FTI's instructions

2.5 FTI has been instructed by Three to test the hypothesis that spectrum value increases with scale, as measured by market share and share of total industry revenue, and that the commercial value of spectrum is a significant driver of spectrum value, in addition to, or instead of, technical value.

2.6 Our analysis is based on information on 323 observations from 80 spectrum auctions including over 220 unique operators in over 50 countries globally. As our focus is to assess outcomes in the context of technical value, we have only collected data from auctions after Q2 2008 and include a considerable amount of high frequency 'capacity' spectrum.

2.7 The data used in this analysis has been gathered from various public and private sources with a wide range of auction and operator variables considered. A full list of data sources is provided in Appendix 1.

Restrictions

2.8 This report has been prepared solely for the benefit of Three for use for the purpose described in this introduction. FTI has agreed with Three that this report may be provided to Ofcom and that it may be published by both Three and Ofcom.

2.9 This report has been drafted by Carl Gustav Gordon, Schellion Horn and Michael Knott and the views expressed in this report are theirs alone.

2.10 FTI accepts no liability or duty of care to any person other than Three for the content of the report and disclaims all responsibility for the consequences of any person other than Three acting or refraining to act in reliance on the report or for any decisions made or not made which are based upon the report.

Limitations to the scope of our work

2.11 This report contains information obtained or derived from a variety of sources. FTI has not sought to establish the reliability of those sources or verified the information provided. No representation or warranty of any kind (whether express or implied) is given by FTI to any person (except to Three under the relevant terms of our engagement) as to the accuracy or completeness of this report.

2.12 This report is based on information available to FTI at the time of writing of the report and does not take into account any new information which becomes known to us after the date of the report. We accept no responsibility for updating the report or informing any recipient of the report of any such new information.

Structure of this report

2.13 In **Section 3**, we set out the background to this study and highlight the importance of spectrum to mobile operators. Following this is an explanation on how auctions are typically used to allocate frequency and a brief overview of Ofcom's PSSR auction in early 2017.

2.14 In **Section 4,** we explain the determinants of the intrinsic value of spectrum to mobile network operators. We set out Ofcom's views, as presented to us by Three, on these determinants, in particular that spectrum value in the PSSR auction may arise from its technical value component (i.e. avoided network costs), which is not expected to increase with the size of an operator. We set out Three's view that the value of high-frequency spectrum has a material commercial value component, and that both technical value (avoided network costs) and commercial value (revenue generation) may increase an operator's size.

2.15 In **Section 5**, we set out the results of the hypothesis we have been asked to test, namely if value of high-frequency spectrum tends to increase with scale, and if value of high-frequency spectrum to some extend is driven by the commercial value component. We set out the methodology for our analysis and the results. [✂-FTI's conclusions.]

2.16 In the **appendices** we provide further details on the data that we have used in our calculations.

3. Background to this study

3.1 This section sets out the background to the forthcoming 2.3 and 3.4 GHz PSSR auction in the UK. It explains the importance of radio spectrum to mobile operators and how the design of an auction can impact the spectrum allocated to each operator. This is followed by a summary of the potential determinants of spectrum value and a summary of the concerns that have been expressed by Three to Ofcom around the design of the PSSR auction.

The importance of mobile spectrum

3.2 Spectrum relates to the radio frequencies allocated to the mobile industry and other sectors for communication over the airwaves. Additional spectrum, including both coverage and capacity bands, means mobile operators can connect more people and offer faster data speeds.

3.3 Spectrum bands have different characteristics, and this makes them suitable for different purposes. In general, low-frequency transmissions can travel greater distances before losing their integrity, and they can pass through walls and buildings more easily. Low-frequency spectrum tends to be more limited in supply. Higher frequency transmissions are capable of carrying more data, but have poor in building penetration.

3.4 While the factors making low-frequency spectrum particularly valuable continue to hold true, its relative scarcity is reducing in many markets as the 700 MHz band starts to be released. Other factors, such as the growing importance of data speeds and overall densification of networks, begin to lessen the relative importance of low-frequency spectrum. Also, the availability of larger contiguous blocks in high-frequency bands is an important factor in the delivery of very high-speed mobile data services.

3.5 Mobile subscribers now consider average data speeds to be among the most important factors in assessing the quality of the service offered to them by different operators[13]. Meeting consumer needs by providing good data speeds can lead to incremental market share and revenues for operators, for example through higher average revenue per user (ARPU). It may also benefit operators in other ways, such as through cost savings related to subscriber acquisition and retention. Having more spectrum enables operators to deliver better data speeds.

[13] Ofcom, The Communications Market Report 2015, page 261

Spectrum auctions as a method of allocating spectrum

3.6 National regulatory authorities (NRAs) allocate and license appropriate spectrum to the services and sectors that need it. A spectrum auction is the most commonly used method to allocate spectrum[14]. It is a process whereby an NRA uses an auction system to sell the rights to transmit signals over specific bands of spectrum and to assign scarce spectrum resources.

3.7 To overcome some of the disadvantages of auctions and to meet broader public interest concerns, NRAs often design auctions with the intention of ensuring they produce a minimum level of competition post-auction. Mechanisms that might be employed include spectrum caps and reserved spectrum.

3.8 Spectrum caps limit the amount of spectrum that any one operator can purchase and are used to ensure that no single mobile operator, or group of operators, can acquire all or most of the spectrum on offer. The goal is to prevent operators from gaining a position in the market through large holdings of spectrum which might lead to anti-competitive impacts such as higher prices for consumers and reduced consumer welfare.

3.9 Spectrum caps were introduced in the 1990s in the Americas, limiting each operator's spectrum holdings, were intended to ensure competition in the early stages of mobile market development – at that time they typically represented about 30% of total allocated mobile spectrum[15].

3.10 In Europe, spectrum caps are not only used as an absolute limit on the amount of spectrum that an operator can hold but also as band specific bidding caps for a specific auction award. For instance, in the Austrian multi-band auction in October 2013, participants were not allowed to win more than 2x35 MHz of spectrum in bands below 1 GHz, 2x20 MHz in the 800 MHz band and 2x30 MHz in the 900 MHz band, while the total spectrum that any one operator could win within the auction was set at 2x70 MHz[16].

[14] Alternatives to auctions include administrative licensing, such as the comparative hearings conducted historically (sometimes referred to as "beauty contests"), or lotteries.

[15] Mobile broadband, competition and spectrum caps, an independent paper prepared for the GSM Association, Arthur D Little.

[16] Spectrum for new entrants, lessons learned, GSMA Intelligence, February 2015

3.11 In the USA, the Federal Communications Commission (FCC) has moved away from absolute spectrum caps to a spectrum screen process whereby competitive objectives are examined on a case-by-case assessment of spectrum aggregation. Under this new approach, the FCC defines a spectrum threshold that triggers an additional review, based on the total amount of spectrum available and the number of existing operators in a market. Unlike a spectrum cap, this spectrum screen is not a bright-line limit since it can vary slightly auction to auction and transaction to transaction, notably when new spectrum bands become available[17].

3.12 An alternative to spectrum caps that has been used by some NRAs is setting aside or reserving spectrum for particular operators, typically new entrants. For instance, in the December 2012 Dutch auction, a set aside of 2x10 MHz in the 800 MHz band and 2x5 MHz in the 900 MHz band was made available for new entrants[18]. Similarly, in the Mexican AWS auction in 2010, a national block of 2x15 MHz was set aside by COFETEL[19].

3.13 Other methods for encouraging competition include different coverage and network deployment requirements for new entrants who purchase spectrum and obligations on existing operators to provide access to infrastructure[20] and national roaming.

The 2017 UK PSSR Auction

3.14 Ofcom is planning to auction 190 MHz of high capacity spectrum in the 2.3 GHz and 3.4 GHz bands. The spectrum being auctioned was previously used by the Ministry of Defence, but has been freed up by the government to make it available for civil uses. This is part of a wider government initiative to release or share 500 MHz of spectrum for civilian use by 2020, which is around the time 5G is expected to start appearing commercially.

3.15 The amount of spectrum being auctioned is equivalent to roughly three-quarters of the spectrum auctioned off by Ofcom at the 4G spectrum auction in 2013. It is expected that this will be used to expand existing data services and also potentially for the future deployment of 5G services.

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17 Op cit.

18 Tele2 won the 800 MHz block whilst the 900 MHz block was not bid for by a new entrant so went to an incumbent.

19 Op cit.

20 This could include site sharing, for example.

3.16 The auction will make available 40 MHz of spectrum in the 2.3 GHz band. This spectrum can be used immediately, since it is already supported by mainstream mobile devices such as the Apple iPhone.

3.17 The auction will make available 150 MHz of spectrum in the 3.4 GHz band. This band is not currently supported by most devices, but it is likely to become useful in around two or three years. Additionally, the 3.4 GHz band is being seen as one of the bands likely to support the initial deployment of 5G mobile services.

3.18 Ofcom intends to auction the spectrum in lots of 10 MHz for the 2.3 GHz band and 5 MHz for the 3.4 GHz band. It will have a reserve price of £1m per 1 MHz in the 2.3. GHz band and £200,000 per 1 MHz in the 3.4 GHz band.

3.19 Ofcom notes that having an uneven distribution of spectrum is not necessarily a barrier to competition between operators. However, Ofcom then notes that a very strong asymmetric distribution of spectrum might lead to competition concerns[21]. Ofcom does not set out a threshold at which spectrum distribution becomes *very* asymmetric as opposed to uneven. However, Ofcom does note that if BT / EE were to win all of the 2.3 GHz spectrum that is available in the auction then its share of spectrum which is immediately useable would increase from 45% to 49% and that this might create a significant risk to competition[22].

3.20 Ofcom notes that it is less concerned with competition risks arising from the 3.4 GHz band. They state that this spectrum is not immediately useable and that by the time that it is, operators will be able to adapt their strategies to find other ways to meet demand[23].

3.21 To address Ofcom's concerns around potential competition risks concerning immediately useable spectrum, Ofcom is proposing to set a cap on immediately useable spectrum of 255 MHz which is 42% of the total of this type of spectrum available and is equal to the current holding of BT / EE of this type of spectrum. Ofcom is not proposing to apply a cap on the amount of spectrum that bidders can buy in the 3.4 GHz band.

3.22 It is expected that all four existing UK mobile networks (O2, EE, Three and Vodafone) are likely to make bids in the auction.

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21 Para 1.21-1.22, Award of the 2.3 and 3.4 GHz spectrum bands. Competition issues and auction regulations, consultation, Ofcom 21st November 2016

22 Para 1.23, op cit

23 Para 1.27, op cit

4. Determinants of intrinsic value and how it varies

4.1 The value drivers of spectrum in auctions may have great impact on how bidding strategies and whether particular operators will enter auctions at a disadvantage. In this section, we outline some sources of high-frequency spectrum value, and how these may change with scale i.e. the market share or share of industry revenue of an operator relative to its competitors. We proceed with setting out how we test which factors drive value of high-frequency spectrum.

Drivers of spectrum value

4.2 The value of spectrum may be derived from two sometimes interlinked value drivers:

(1) **Strategic value,** which may be defined as the present value of additional expected profits earned from bids aimed at affecting the future structure of competition in mobile services by depriving one or more competitors of spectrum; and

(2) **Intrinsic value,** which may be defined as the present value of additional profits a bidder expects to earn when holding the spectrum versus not holding it, absent of strategic considerations.

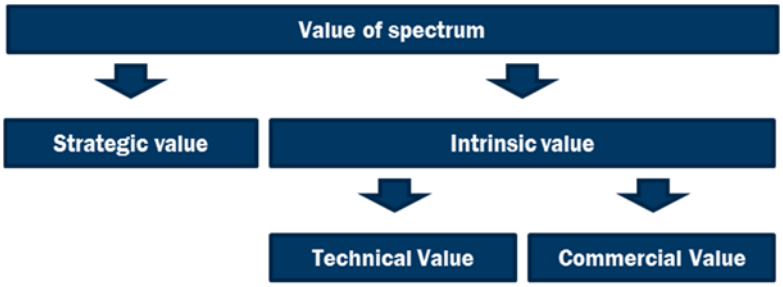
4.3 Intrinsic value may be further broken into two value drivers[24]:

i) **Technical value**, which reflect the network cost savings that additional spectrum can generate for providing a given level of coverage or capacity; and

ii) **Commercial value,** which is the value attained from allowing operators to provide additional or improved services, such as greater speeds with carrier aggregation, and thereby generate revenues to the operator.

[24] Spectrum valuation: critical strategic, technical and commercial factors for operators and regulators, Analysis Mason, March 2012

Figure 1: Technical and Commercial Value of Spectrum



Source: FTI Consulting

Technical value and views on how it varies with scale

4.4 Technical value reflects that spectrum and radio equipment are partial substitutes. When demand for network capacity outstrips supply, an operator will to some extent have the option to increase capacity by building a new sites or acquiring more spectrum. Holding additional spectrum reduces the need for new sites and therefore avoids the additional costs of site build such as planning applications, site leases, and infrastructure and radio access equipment.

4.5 In the absence of any strategic value component, if the same services are provided to the same customers with or without spectrum then there is no commercial value and only technical value.

4.6 Regarding the relationship between technical value and spectrum holdings, we understand from Three that Ofcom has stated that technical value will (all other factors being equal) decline as an operator holds more pre-auction spectrum. This is because the avoided network cost is likely to be greater for an operator with low levels of pre-auction spectrum compared to competitors with more.

4.7 However, there are different views with regards to how technical value varies with scale, in terms of increasing numbers of subscribers.

4.8 FTI understands that Three has previously intonated that technical value will increase as the expected future level of traffic across the network increases. Keeping everything else equal, this would imply that an operator with more subscribers would have higher levels of traffic across its network. Hence, there should be a positive relationship between market share of an operator and its technical value compared to competitors.

4.9 Three has told FTI that Ofcom suggests that if spectrum is mainly used for mitigating capacity constraints then the extent to which technical value varies is driven by the number of capacity constrained sites an operator has now or in the future. Therefore, the operator with the highest technical value would be the one who has, or will have, the most capacity constrained network. We understand that Ofcom also notes that this is not necessarily the operator with the largest number of subscribers or the highest level of network traffic. In other words, Ofcom asserts that there is a positive relationship between how capacity constrained an operator's network is and the technical value it assigns to spectrum.

4.10 In summary, we understand that Three expects a significant part of the intrinsic value to increase with an operator's size whereas Ofcom notes that this may not always be the case and that, rather, technical value is driven more by how capacity constrained an operator is. We also understand that Ofcom notes that this may not necessarily vary with scale.

Commercial value and perceptions on how it varies with scale

4.11 The commercial value of spectrum reflects that more spectrum allows operators to generate increased ARPUs, reduce subscriber acquisition and retention costs and / or increase their market share. It can be hard for operators to achieve these commercial benefits without having sufficient spectrum[25]. In particular, the cost of improving network performance (i.e. increasing average user speeds) without new spectrum may be so high that it is unprofitable to attempt to do so. Hence, the quality of services that an operator offers may be determined by how much spectrum it acquires.

4.12 We note that if an operator can only use the spectrum to improve its services, then the intrinsic value will consist only of commercial value and not technical value.

4.13 One view is that the commercial value will tend to increase with subscriber numbers, as the benefits will be generated over a larger customer base. That is, there is a positive relationship between commercial value and market share.

[25] We note that if spectrum could only be used to offer improved services or access which it could not provide without the spectrum, then the intrinsic value will only be driven commercial value and not technical value.

4.14 However, we understand from Three that Ofcom stated that it may not always be the case that commercial value increases with the number of subscribers. We understand that Ofcom argues that the larger the subscriber base, the less of the new spectrum there will be per subscriber, which is important if the amount of spectrum per subscriber affect the quality of service.

4.15 Hence, we understand that Three expects commercial value to increase with an operator's scale whereas Ofcom argues that this may not always be the case.

Value drivers of PSSR spectrum specifically

4.16 We understand from Three that Ofcom anticipates that the 2.3 and 3.4 GHz spectrum will be used mainly for capacity rather than for providing new types of services, and that the technical value will be more important than the commercial value. This may be because an operator, without the spectrum, will be able to provide very similar services only by spending money to expand its network.

4.17 As a result the value of PSSR spectrum should be more similar to the value of high-frequency 'capacity' spectrum (above 1400 MHz) than the value in lower frequency bands (1400 MHz and below). We understand from Three that this corresponds with Ofcom's views.

4.18 Moreover, we understand from Three that Ofcom suggests that if the intrinsic value is driven by technical value and not commercial value, then it is unlikely that there is a material strategic value component to PSSR spectrum.

4.19 To summarise the information we have from Three, we understand that Ofcom's view is that strategic value should not play a role in the PSSR auction and that technical value is the key driver of the value of high-frequency 'capacity' spectrum and, as a result, there should not necessarily be a relationship between spectrum value and market share. We understand that Ofcom expects to see that the value of this high-frequency spectrum will increase as an operator is more network constrained and holds less pre-auction spectrum.

Testing how value of high-frequency spectrum increases with scale, and the importance of technical and commercial value

4.20 When assessing if value of high-frequency spectrum varies with the scale of an operator, we consider the operator's market share in a given market as a proxy for its size. We aim to test the relationship between market share and outcomes in auctions containing a significant portion of high-frequency 'capacity' spectrum. In these auctions, we specifically consider the operator's share of high-frequency spectrum acquired and the expenditure on high-frequency spectrum relative to competing bidders.

4.21 Assuming we observe a positive relationship between market share and outcomes in high-frequency spectrum auctions, and the assertion that technical value does not increase with size is true, then any increases in value must be driven by either commercial value and / or strategic value.

4.22 If we subsequently find that there is a positive relationship between an operator's market share and its ex-ante or 'forecasted' margins, this would imply that the commercial value component should be larger for larger operators i.e. increase with scale. In this case, it is likely that high-frequency spectrum contains a material commercial value component as the business model for serving additional customers is better. We set out to test the relationship using the pre-auction EBITDA-margin as a proxy for an operator's ex-ante margins[26].

4.23 However, if we observe that operators that are more capacity constrained, or have lower pre-auction spectrum holdings, tend to acquire or spend more in high-frequency auctions, then we would be able to conclude that spectrum value is driven, at least in a significant part, by technical value. We test this relationship by:

(1) Considering if there is a relationship between pre-auction spectrum holdings and auction outcomes; and

(2) Considering if there is a relationship between network utilization and auction outcomes. We use relative network utilization as an indicator of how capacity constrained an operator is compared to competing bidders. We approximate this by an operator's level of traffic per MHz spectrum available relative to competing bidders.

4.24 While this is an empirical study on average tendencies from auctions including high-frequency bands globally, we acknowledge that the arguments presented by Three and Ofcom may be relating to the 2.3 and 3.4 GHz PSSR spectrum in a UK context.

4.25 We also acknowledge that the analysis undertaken cannot prove the existence of commercial value per se, since any relationship between an operator's scale and auction outcomes could be because (i) technical value increases with an operator's market share and / or there is a material strategic value component to high-frequency spectrum. These causes would be in contrast to Ofcom's assumptions as presented by Three to FTI.

[26] We acknowledge that EBITDA-margins not reflect ex-ante or 'forecasted' margins, as this figure also depends on business strategy, forecasted competition, etc.

5. Analysis and results

Assessing the importance of market size and the relevance of commercial value in auction outcomes

5.1 To assess whether there is a relationship between the scale of an operator and outcomes in high-frequency auctions, we investigate how an operator's market share may impact the proportion of spectrum it wins and its share of total expenditure in the auction.

5.2 If commercial value drives spectrum value then we would expect to see a positive relationship between pre-auction market share and share of total expenditure and / or proportion of spectrum won[27].

5.3 To further assess whether commercial value is a significant part of the intrinsic value of capacity spectrum, it is worthwhile considering if a profit-generating metric may have an impact on auction share of spectrum won and / or expenditure. However, as larger operators tend to have larger ex-ante margins, this effect may be captured in an operator's market share. To verify this effect against our dataset, we compared operators' EBITDA-margins and market shares at the time of auction.

5.4 In our data set, market share is defined as the operator's share of mobile connections[28] in a given country[29]. The dependent variables considered were:

(1) Operator's total winning share of spectrum available in auctions containing high frequency spectrum (share of spectrum);

(2) Winning share of the high-frequency capacity spectrum available (share of high-frequency spectrum); and

[27] We recognise that a positive relationship between these variables could also arise from technical or strategic value as discussed in the previous section.

[28] We exclude M2M connections.

[29] An operator's scale or market dominance may also be estimated using share of total industry revenue rather than market share of connections. Hence, we repeat our analysis using share of total industry revenue to cross check our results.

(3) Proportion of total expenditure by all participants in the auction (share of spend)[30].

5.5 There may be great variation between how much spectrum is offered in each auction and the value of spectrum in different markets. We therefore consider the share of expenditure and winnings relative to competing bidders in a given auction.

5.6 In many cases, larger operators are constrained by caps when bidding in auctions. For each auction, we identified whether a cap was present or not, and for each operator in each auction we assessed whether or not it was constrained by this cap. We included dummy variables in our dataset to reflect this.

5.7 To estimate the relationship between market share and auction outcomes we made use of a simple regression analysis. Should the value of high-frequency spectrum increase as operators gets larger, we would expect to see a significant positive relationship between the size of an operator, the amount of spectrum won in high-frequency spectrum auctions and its share of total expenditure. This relationship should strengthen as we adjust for operators that were constrained by a cap in the bidding procedures.

5.8 As many factors affect outcomes of spectrum in auctions, such as income per capita, planning regulations and number of competitors, we would only expect a minor degree of variance in auction outcomes to be explained by market shares[31].

Method for assessing the relevance of technical value

5.9 To assess whether the intrinsic value of spectrum is driven by technical value we consider how capacity constrained an operator is compared to its competitors. If technical value is a material driver of intrinsic value for capacity spectrum, we expect that operators with a higher degree of network utilisation would both buy more and spend more on high frequency capacity spectrum. This is because the amount an operator spends on acquiring spectrum outweighs the costs of building out a network with more cell sites. Similarly, we expect that operators with lower pre-auction spectrum holdings would win more spectrum and spend more on it, as discussed in the previous section.

30 A high correlation is expected between share of spectrum acquired and share of expenditure.

31 In technical terms, this means that we would expect a low R-squared value.

5.10 To determine the extent to which an operator is network constrained relative to its competitors we have estimated operators' network utilisation at the time of an auction. Utilisation has been calculated as network traffic, in terms of gigabyte throughput per quarter, divided by the operator's spectrum holdings, at the time of the auction[32].

5.11 We acknowledge that more factors affect operators' network utilisation, for example the number of cell sites; however, we were unable to collect historical data on cell sites for a meaningful number of operators. We also expect the number of cell sites to be strongly correlated with an operator's level of traffic, which is included in our calculation of network utilisation.

5.12 For each operator in a given country we considered historical traffic figures[33]. We also estimated historical spectrum holdings by combining current data and information with information on previous allocations, spectrum repurposing, license expiry and mergers. To calculate utilisation for a given point in time, we divided an operator's network traffic with its total spectrum holdings.

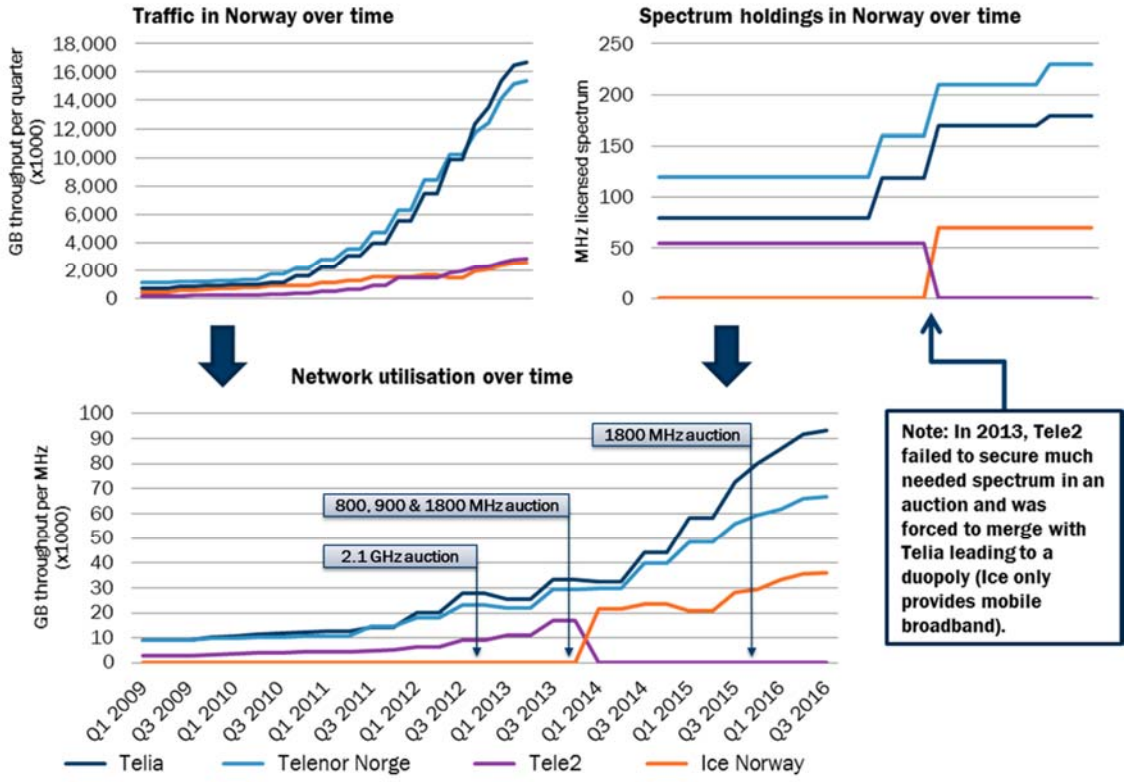
5.13 We have illustrated this in Figure 2 below using Norway as an example. To estimate network utilisation over time, we divide historical traffic data (as illustrated by the graph in the upper left corner) with historical spectrum holdings (as illustrated by the graph in the upper right corner)[34].

[32] According to Three, traffic per MHz spectrum held should be a good estimator of how constrained an operator's network is. However, we understand that this is a proxy variable, and there may be factors such as density of network, service areas etc., which is unaccounted for.

[33] In cases where we had information on an operator's traffic relative to its competitors, we would estimate traffic figures for this operator at the time of auction.

[34] We note that Tele2, then the smallest operator in the market, failed to secure spectrum at a spectrum auction and was forced to merge with Telia, the then second largest operator. As a result its utilisation for Tele2 is set to zero from Q1 2014. Ice, a new mobile broadband provider, won a large portion of spectrum in the same auction.

Figure 2: Network traffic, spectrum holdings and network utilisation in Norway



Source: FTI analysis based on publically available data
Note: For Norway, we have nine observations for 4 different operators in three different auctions.

5.14 To adjust for variations between countries in terms of population, tariff structures and similar, we have only considered an operator's network utilisation relative to other operators, for which we had data, within a particular country.

5.15 To estimate the relationship between network utilisation and auction outcomes, i.e. share of spectrum acquired and share of total expenditure, we made use of a simple regression analysis. Should technical value be a significant driver for intrinsic value of high frequency spectrum, we would expect to see a significant positive relationship between an operator's network utilisation relative to its competitors, the amount of spectrum won in high frequency spectrum auctions and its share of total expenditure.

5.16 Similarly to when testing for commercial value, since many factors affect the value of spectrum in auctions such as strategic value, we would only expect some variation to be explained by relative network utilisation.

Data collection

5.17 In order to assess our hypotheses, we collected data on market shares by number of connections at the time of the auction, amount of spectrum won by each operator in different frequency bands, price paid for the spectrum, and whether an operator was constrained by a cap or not in the auction. We also collected data on operator and total industry revenues to estimate each operator's share of total market revenue at the time of the auction.

5.18 We collected data on 80 award procedures from Q2 2008 including 223 participating operators across 52 countries. The dataset included 323 observations, where an observation is data for one participating bidder in a given auction.

5.19 As our primary focus is high frequency 'capacity' spectrum, we only considered award procedures that included a significant portion of spectrum above the 1400 MHz band[35].

5.20 Although we collected information on bidder participation, If a bidder does not win any spectrum in an auction, it is often infeasible to assess whether that participating bidder was intending to actively compete. In several cases, bidders filling to participate in auctions have dropped out in the first round or even before the auction has started. For example:

(1) In 2013 Citycell qualified for the Bangladeshi 2.1 GHz auction but did not pay a deposit and pulled out before the start of the auction;

(2) In 2015, Hubb Investments qualified for the Polish 800 MHz and 2.6 GHz auction but did not bid;

(3) In 2015, Netgsm entered the Turkish multiband auction but did not bid; and

(4) In 2013, Vodafone Hutchison entered the Australia 700 MHz and 2.6 GHz auction but pulled out before it began.

5.21 To address this, we only considered bidders that won some amount of spectrum in the award procedure. We excluded 27 non-winning operators on the basis that we could not verify whether they were actively competing in an auction.

[35] According to Three, spectrum above the L-band/1400 MHz band is often considered as 'capacity' spectrum as opposed to 'coverage' spectrum.

5.22 In ten instances, the auctions were so-called 'all-or-nothing' auctions where one bidder either won all of the spectrum available, or nothing at all. These auctions tended to include very limited amounts of spectrum (30 MHz or less). In eight of these ten cases only one bidder was confirmed to participate. In the remaining two cases, only one block of 10 MHz of spectrum was available in the auctions. On the basis that we were interested in assessing how much an operator was likely to pay or how much spectrum it was likely to win relative to its competitors, we excluded these auctions as outliers[36].

5.23 We also excluded Yoigo in the Spanish 900 and 1800 MHz auction in May 2011 as an outlier on the basis that competition was very limited in this auction due to caps and set asides.

5.24 Once the above adjustments to the dataset were made, the dataset included information on market shares and winnings form 70 capacity spectrum award procedures since Q2 2008 including 177 operators across 49 countries. We had 236 observations in total.

5.25 In most of these cases we were able to identify the price paid for the spectrum, whether a cap was present or not, and whether a particular operator's bidding was restricted by the cap[37].

5.26 We collected data on EBITDA-margins for 99 operators in 59 auctions across 42 countries. This included 128 observations in total.

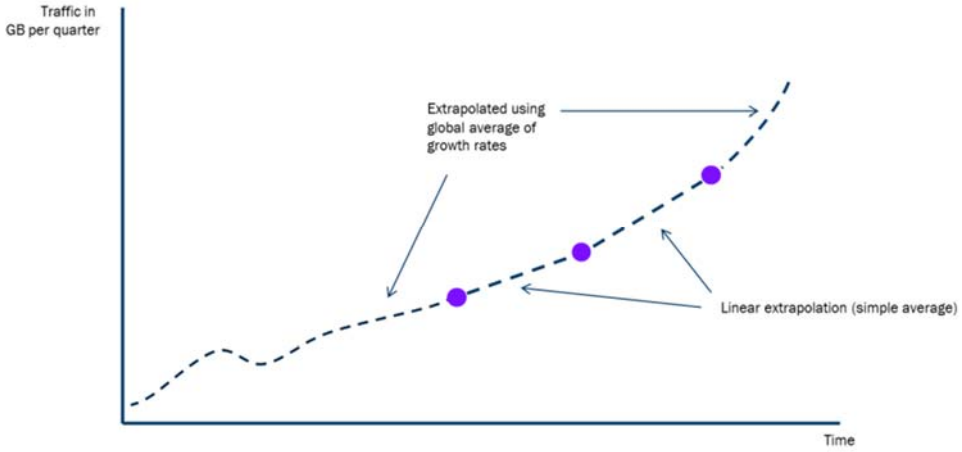
5.27 We also collected data on network traffic and spectrum holdings to estimate network utilisation at the time of auction. We estimated historical spectrum holdings using operators' current spectrum holdings and adjusting for allocations, repurposing and expiry since 2007. Our dataset included 120 observations of pre-auction spectrum holdings for 106 operators across 48 auctions in 36 countries.

5.28 In some cases, the traffic figures available did not correspond exactly to the time of auction. When necessary, we interpolated linearly between data points and extrapolated using global trends whenever we had data either before or after an award procedure, as illustrated in Figure 3 below.

[36] In eight out of ten cases where the operator was awarded all the available spectrum, this operator was the largest market player. Hence, we conclude that excluding these may only impact our results conservatively.

[37] We identified caps in 62 auctions, and in 48 of these we were able to identify whether a bidder was constrained by the cap or not. We had complete price information for 63 auctions.

Figure 3: Estimating historical traffic figures from existing data points



Source: FTI Consulting

5.29 The analysis was based on relative utilisation figures and included 87 observations for 64 participating and winning operators across 34 auctions in 23 countries since Q2 2008. This does not include auctions in markets where we had utilisation data for less than two participating operators.

[✂-FTI's conclusions.]

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Figure 4: [✂]

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Figure 5: [✂]

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38 In this analysis, we have included new entrants and assigned these a market share of zero. If we exclude these new entrants we find a slight increase in both effect and R-squared.

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Figure 6: [✂]

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Figure 7: [✂]

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[✂][49]

Figure 8: [✂]

[✂][✂]Figure 9: [✂]

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Appendix 1: Key data sources

A1.1 Numerous data sources were accessed to compile the data required to undertake the analysis. These sources were found using a combination of online research, previously accessed databases and information from Three.

Table A1-1 List of key data sources

Source	Description
GSMA Intelligence database	Provided information about operators in a market at a given time. This include historical data on mobile data traffic by operator, on number of connections by operator and by country (which was used to calculate market shares), and some historical information on EBITDA margins.
Enders Analysis and tefficient.com	Used for supplementary data on mobile data traffic by operator. Minor variations may occur in data that was recorded from charts.
Bank of America Merrill Lynch's Global Wireless Matrix	Provided historical data on CAPEX by operator, supplementary information on EBITDA margins by operator, yearly average exchange rate from the local currency in a country to historical USD, supplementary information on market shares, and supplementary information about operators in a market.
NRA websites	Contained auction information from information memorandums and press releases on auction outcomes and rules. Data extracted includes auction lots, auction format, auction participants, reserve prices, spectrum caps, lot winners and prices paid.

Three	Data on current spectrum holdings was given to us by Three based on information from spectrum tracker, PolicyTracker, Cullen International, spectrummonitoring.com, Analysis Mason, and our own research. FTI has amended this information extrapolated the information back to 2007 controlling for spectrum repurposing, expiry, and acquisitions in each of the 50+ countries considered in the analysis.
PolicyTracker database	Used PolicyTracker's database as a list of auctions completed. This information was supplemented by own research.
European Communications Office Frequency Information System	Used for supplementary information on current spectrum holdings by operator and to verify the information provided by Three.
Other online sources such as ministerial websites, telecoms newsletters etc.	For information on auction results, historical exchange rates, historical populations data and similar.
Quality Assurance	In particular relating to auction outcomes and price, we aimed to cross check information against at least two sources.

Appendix 2: Spectrum Auction examples

Austria

In October 2013 the Austrian Regulator, RTR, completed a multiband spectrum auction in the 800 MHz, 900 MHz and 1800 MHz spectrum bands. The auction was a Combinatorial Clock auction where all spectrum was sold in 2x5 MHz bands. The three incumbent mobile operators were the only participants in the auction. The results are set out below:

Operator	800 MHz	900 MHz	1800 MHz	Price Paid (€m)	Price/Mhz/Pop (€)
Telekom Austria	2x20	2x15	2x35	1,029.9	0.868
T-Mobile Austria	2x10	2x15	2x20	654.5	0.858
H3G Austria		2x5	2X20	330.1	0.779
Total Available	2x30	2x35	2x75		

RTR restricted operators in the auction via spectrum caps. A total cap of 2x70 MHz per operator was set, alongside a 2x35 MHz sub 1-GHz cap, a 2x20 MHz in the 800 MHz band and a 2x30 MHz cap in the 900 MHz band. Telekom Austria bought the maximum spectrum available to them in the auction, while T-Mobile Austria and H3G Austria did not hit any caps.
Telekom Austria, who were the largest operator in Austria at the time of the auction with 43.6% of total subscribers, won half of the total spectrum available and spent more than the other two incumbents combined. In contrast, H3G who were the smallest incumbent with a 25.7% share of subscribers and capital expenditure four times lower than Telekom Austria, won only 2x25 MHz of spectrum in total. This included failing to win any spectrum in the 800 MHz band, which had the highest reserve price in the auction and hence was the most sought after spectrum.

Switzerland

Comreg, the Swiss regulator, held a Combinatorial Clock auction for the sale of spectrum in the In the spectrum bands in February 2012. Overall 605 MHz of spectrum was made available to the 3 participating incumbent operators. The spectrum was sold in blocks of various sizes. The results of the auction are outlined below.

Operator	800 MHz	900 MHz	1800 MHz	2.1 GHz	2.1 GHz TDD	2.6 GHz	2.6 GHz TDD	Price Paid (CHFm)	Price/Mhz /Pop (CHF)
Orange	2x10	2x5	2x25	2x20		2x20		154.7	0.121
Sunrise	2x10	2x15	2x20	2x10		2x25		481.7	0.376
Swisscom	2x10	2x15	2X30	2x30		2x20	1x45	359.8	0.176
Total Available	2x30	2x35	2x75	2x60	1x20	2x70	1x45		

Operators were restricted in their bidding by spectrum caps of 2x135 MHz of total paired spectrum, 2x25 MHz sub 1-GHz, 2x20 MHz in the 900 MHz band, 2x35 MHz in 1800 MHz band and 2x30 MHz in 2.1 GHz band. Sunrise and Swisscom hit the sub 1-GHz cap and only Swisscom hit the 2.1 GHz cap.
From the results, it is clear that Sunrise underperformed in this auction. Swisscom, who have a 62.0% of Swiss subscribers, paid 25% less than Sunrise for their winnings while obtaining significantly more spectrum. Swisscom won 2x10 MHz more than Sunrise in the 1800 MHz band, 2x20 MHz more in 2.1 GHz band, 2x5 MHz less in the 2.6 GHz band and 1x45 MHz more in the 2.6 GHz band. In fact, Swisscom, who have considerably more market share than the other two incumbents, won 255 MHz of spectrum in the auction, 95 MHz more than both Orange and Sunrise.
Sunrise and Orange had similar market shares at the time of the auction, of 21.6% and 16.4% respectively, however Orange also got a much better deal than Sunrise. Sunrise paid over 3 times as much as Orange for 2x10 MHz more in the 900 MHz band and 2x5 MHz more in 2.6 GHz band but 2x10 MHz less in 2.1 GHz band and 2x5 MHz less in 1800 MHz band.

The Netherlands

In December 2012 a multiband spectrum Combinatorial Clock auction was held in The Netherlands which included spectrum in the 800 MHz band, 900 MHz band, 1800 MHz band, 1900 MHz band, 2.1 GHz band and 2.6 GHz band. The Dutch market contained five operators at the time of the auction, all of whom participated in the auction. Lots were sold in 2x5 MHz bands, the results are below:

Operator	800 MHz	900 MHz	1800 MHz	1.9 GHz TDD	2.1 GHz	2.6 GHz TDD	Price Paid (€m)	Price/Mhz/ Pop (€)
KPN	2x10	2x10	2x20		2x5	1x30	1,350	0.670
Vodafone	2x10	2x10	2x20		2x5		1,380	0.913
T-Mobile		2x15	2X30	1x14.6		1x25	911	0.418
Tele2	2x10						161	0.479
Ziggo								
Total Available	2x30	2x35	2x70	1x14.6	2x10	1x55		

A set aside of 2x10 MHz in the 800 MHz band and 2x5 MHz in the 900 MHz band was made available for new entrants. Tele2 won the 800 MHz block, the 900 MHz block was not bid for by a new entrant so went to an incumbent.
KPN was the largest incumbent in The Netherlands at the time of the auction with a 48.4% market share of subscribers, compared to Vodafone, the second largest incumbent with a 27.7% market share. KPN obtained a significantly better deal than Vodafone in the auction, paying €30m less than Vodafone and winning an extra 30 MHz of TDD spectrum. Both Vodafone and KPN spent substantially more in the auction than the other participants, including incumbent T-Mobile.

Ireland

The Irish regulator, Comreg, held a 800 Mhz, 900 MHz and 1800 MHz Combinatorial Clock auction in November 2012. All 4 incumbents in the Irish market competed in the auction. Spectrum was sold in 2x5 MHz lots, and across two time periods (2013-2015 and 2015-2030). The results outlined below show the winners of the 15 year licenses from 2015:

Operator	800 MHz	900 MHz	1800 MHz	Price Paid (€m)	Price/Mhz/ Pop (€)
Meteor Mobile	2x10	2x10	2x15	145	0.451
Vodafone	2x10	2x10	2x25	161	0.389
Telefonica	2x10	2x10	2X15	125	0.389
H3G		2x5	2x20	51	0.222
Total Available	2x30	2x35	2x75		

There was a 2x20 MHz cap in the auction on sub 1-GHz spectrum winnings, which was binding for all incumbents except H3G. There was a total cap of 2x50 MHz for the whole auction; however this cap was not met.

Vodafone was the largest operator in Ireland at the time of the auction, with a 42.9% share of total subscribers. Further to this, Vodafone won the most spectrum in the auction and also spent the most. In contrast, H3G was the smallest incumbent with 9.6% market share of subscribers. H3G won the smallest amount of spectrum and spent the least in the auction.

Appendix 3: Impact of revenue share on auction outcomes

[✂-Supplementary detail on FTI's conclusions.][51]

Figure A1: [✂]

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Figure A2: [✂]

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Figure A3: [✂]

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