Annex 9: Technical modelling provides additional and important datapoints on the value of spectrum

Introduction and summary

Ofcom has chosen not to make any use of technical modelling as a means of assisting it in determining the market value of 900MHz and 1800MHz mobile spectrum. Ofcom has merely concluded that technical cost modelling is difficult and that it has good enough data from the UK auction and from international benchmarking to be able to not consider its use in the present circumstances. We consider the latter point elsewhere in Vodafone response – this annex addresses the benefit that technical modelling could provide and should have provided to Ofcom in the present spectrum valuation issue.

Technical cost modelling is Ofcom's widespread method of choice for valuing spectrum and setting spectrum fees in conditions of spectrum scarcity in all other spectrum bands (by the charging of AIP), for determination of spectrum use between competing alternatives, for deriving reserve prices for the Auction, and more widely, very extensively in wholesale charge controls for example through the very large and complex MTR model. Its approach in these proposals is, therefore at considerable odds with Ofcom's general espousal of the use of technical modelling. We consider this in more detail in section 1 below.

In principle, as we show below in section 2, the AIP method used by Ofcom for valuing other spectrum, which is aimed at uncovering the price that would emerge in a well-functioning market, is entirely consistent if not identical to the conceptual framework of the SI that Ofcom sets out in the current consultation. However in practice, the provisional fee that Ofcom has derived for mobile in the present consultation is very much different from the fee that Ofcom is proposing to set for DTT, even where that has been calculated in relation to the mobile use of DTT spectrum. This error is at significant odds with Ofcom's duties of efficient fee setting.

Vodafone believes that Ofcom has exaggerated the difficulty of modelling. We explain this view in section 3 below. Ofcom's criticisms of the effectiveness of modelling in this consultation are incorrect and misdirected. Ofcom is using an obvious known issue of single frequency coverage modelling in terms of the potential uncertainty of how many sites are required for mobile coverage for a given band as a reason not to embark on the modelling. However the problem that Ofcom describes is irrelevant in the current circumstances where the decision as to how many sites will be initially built has already been determined by the UK operators. In this context it is a capacity modelling approach that is in fact currently required. Such a method has been used for example by the Ofcom annual spectrum fee review in 2004 on a single band basis, and the Analysys Mason DTT 700MHz modelling in 2013 on a multi-band basis.

In the case of the 700MHz spectrum, Ofcom has been able to use a model, that it commissioned from Analysys Mason, which calculates the value to mobile operators of using that spectrum. This model is considered in more detail in section 4 below. As we there argue, 700MHz may well be seen as a better proxy for 900MHz than 800MHz. We consider therefore that the outputs from the 700MHz model, that show a valuation of approximately £9m per MHz, can provide a useful indication of the value of 900MHz spectrum. However there are correctible errors in the Analysys Mason model which suggest that these results are on the high side of what would be calculated by a model specifically developed to examine the value of 900MHz spectrum to mobile operators in the UK.

Ofcom's failure to even attempt to construct such a purpose built model to consider the value of 900MHz or adapt the existing 700MHz model is inexplicable and in error. We show below in section 5 the necessary main components to such a model.

We can be confident that any properly constructed model would generate values similar to or lower than those calculated in the Analysys Mason DTT model. We are very clear that such a model would not generate a value of 900MHz spectrum (or for that matter 1800MHz spectrum) anything like as high as that currently estimated by Ofcom, except in a totally unrealistic assumed outcome of very high future traffic volume and very low future spectrum supply. Given that this outcome is one that Ofcom is taking extensive steps to avoid, particularly through the release of additional spectrum to minimise any risks of a "capacity crunch" it would require an assumption of regulatory failure for such a high valuation of the spectrum to prevail.

Our conclusion from this annex is that a properly constructed cost model would yield a value of 900MHz spectrum below the level currently shown by our analysis of the auction data of £12m to £15.9m. This suggests that if the auction methodology continues to be used as the sole approach, then the value of 900MHz to be adopted should at most be £12m.

Annex 9: Technical modelling provides additional and important datapoints on the value of spectrum

1. The widespread use of modelling for valuing spectrum

Technical modelling has in practice been used quite extensively by Ofcom and by other NRAs in many areas and for many years to value spectrum. Ofcom's failure to do so here is inexplicable.

In previous setting of 900/1800MHz spectrum fees

Previous 900/1800 spectrum fee setting by Ofcom and Oftel has made use of technical modelling. This was initially based on the Smith Nera STU (Spectrum Tariff Unit) which as the Ofcom SRSP statement described involved "calculating reference rates based only on "own-use" opportunity cost"[1]. Subsequently the method was extended (under the "Indepen" approach) to include as well the opportunity cost of feasible alternative use. An Indepen based opportunity cost technical model was presented by Ofcom in 2004 as being appropriate for the setting of 900MHz and 1800MHz spectrum prices. The model was subsequently enhanced and developed by Vodafone using more accurate Ofcom modelling data sourced from the MTR model that had been adopted by Ofcom for the then current MTR charge control.

Both the Indepen and Vodafone models examined the impact on an average efficient operator of adding or subtracting a small increment of spectrum in terms of the additional or subtractional network build that would arise from that change. In this particular instance, the only possible mobile use for the 900/1800MHz spectrum at the time was for 2G[2]. At that time the only other alternative mobile technology was 3G, but no 3G mobile devices or network equipment were then available for use at 900MHz and 1800MHz.

In fact Vodafone was able to show from its 2004 model that given that 2G was the only available mobile technology in the 900MHz and 1800MHz bands, and employing Ofcom's forecast of customer and traffic migration from the legacy 2G to the emerging 3G technology, and Ofcom's view of network build cost and overall traffic, that a low value should be ascribed to the last increments of spectrum[3], and that thus if anything the existing fees that were based on the Smith Nera STU were likely to be excessive. We understand it was for this reason that Ofcom declined to continue with its provisional 2004 proposal based on the original (factually incorrect) Indepen model to significantly increase the spectrum fee charged to mobile operators for 900/1800MHz.

It is worth noting that the modelling analysis of both Indepen and Vodafone with respect to the increments of spectrum was purely traffic capacity based, and thus was concerned with only those parts of the UK where the network build was dimensioned by traffic. Coverage was quite rightly deemed to be addressed by the non-incremental spectrum – thus the issue of coverage was not a component of the technical cost modelling, either of Vodafone or of Ofcom. Indepen reported:

[1] Ofcom SRSP: The revised Framework for Spectrum Pricing, December 2010 at paragraph 5.93

[2] This arose in part from the fact that the spectrum was only licenced for use for 2G, but furthermore irrespective of the licence restriction there was no alternative mobile technology available for UK use in the 900/1800MHz bands in 2004.

[3] In the case of 2G the spectrum increments were measured in paired 200KHz carriers

> *"The value is based on the infrastructure costs an operator might save if assigned an additional 2 x 2.4 MHz of spectrum (the equivalent of a single channel per sector assuming a four-cell per cluster, three sector per cell network configuration). It is assumed this spectrum would be used to relieve congestion in urban hotspots. Cost and traffic data come from the LRIC model Analysys developed for Oftel. The network is assumed to be mature (i.e. cell sizes are determined by capacity rather than coverage considerations) and* ***so marginal values are the same for 900 and 1800 MHz networks****.[4]"*

Thus Indepen's view in 2004 was that there was no difference under 2G technology between 900MHz and 1800MHz for providing incremental capacity, and hence no difference in their relative values. We discuss below Ofcom's view of this with respect to 4G data services.

Other uses of technical cost modelling by Ofcom

Technical cost modelling has been used very recently by Ofcom for an evaluation of alternative uses of part of the DTT band, where it is mobile that is the alternative use to DTT that is under consideration. Ofcom has commissioned from Analysys Mason a model on 700MHz alternative use[5]. This model (and the matching model on the value of DTT's use of the same spectrum) formed not only the key component of Ofcom's provisional view in March 2013 that 700MHz has significantly more value in use as mobile spectrum rather than as DTT spectrum, but also was used by Ofcom to provide a suggested alternative use opportunity cost based spectrum fee for the remaining spectrum in the UHF band[6].

It is worth noting that the Analysys Mason mobile 700MHz model is more complex than a simple single frequency model such as the Vodafone/Indepen models of 2004. The model is however much less complex than other established models actually used by Ofcom in charge control decisions, such as the 2011/12 MTR model. It is a multi-band long run model that considers the future impact on network build of adding various quantities of 700MHz spectrum to an operator's existing portfolio of multiple spectrum bands. The principle however that is used, of examining the consequences of incremental spectrum on network build, is at a high level very similar to the 2004 models.

But this is not the only recent occasion on which Ofcom has made use of technical cost modelling with respect to mobile spectrum valuation. It was clearly necessary to set reserve prices for the recent Combined Auction. To assist with this, Ofcom commissioned from DotEcon and Aetha a study aimed at recommending a plausible range of spectrum values suitable for reserve price setting. DotEcon and Aetha conducted two separate exercises for this: an analysis of international auction benchmarks, which has been largely recycled in the very similar 2013 exercise by DotEcon for the present consultation, and a cost modelling piece by Aetha, which has not. In fact very limited reference to this part of the DotEcon and Aetha 2012 work has been made in the present consultation. This may in part be because the modelling was

[4] An economic study to review spectrum pricing: Indepen, Aegis Systems and Warwick Business School February 2004, at page 59. Vodafone emphasis of the last phrase

[5] Analysys Mason; Opportunity cost of the spectrum used by digital terrestrial TV and digital audio broadcasting, a final report for Ofcom March 2013

[6] Ofcom Spectrum pricing for terrestrial broadcasting, consultation, March 2013, at paragraph 5.11, and the Analysys Mason report at page 1

quite reasonably very heavily redacted prior to the auction (since it contained an estimation of each individual operator's value of the to-be-auctioned spectrum).

In the context of the present consultation, Vodafone requested sight of the original unredacted 2012 report, and subsequently the model itself. Ofcom provided both of these. The Aetha model is focused on alternative auction outcome scenarios, and is based on examining the impact of incremental auction spectrum on coverage and capacity provision and on the resulting share of 4G revenue. But the point here of relevance is that Ofcom made use of the outputs of technical cost modelling to assist it in setting reserve prices. Clearly then, Ofcom has seen benefit in the past in applying cost-modelling to assess the appropriate values of 900 and 1800 MHz spectrum. The Aetha model is of very limited use in the present post-auction context, given the sea change that has occurred in the spectrum portfolios of the mobile operators as a result of the auction[7], but it is a useful illustration of Ofcom's use of technical modelling to derive spectrum value.

Ofcom has declared in the SRSP spectrum fee review statement of December 2010 that as a general principle, where spectrum scarcity has been established, it will use a technical cost modelling based opportunity cost approach to setting the fees for such spectrum. Where spectrum scarcity is not established, then it will set fees at a level designed to recover the appropriate proportion of Ofcom's own costs that relate to the particular band in question. There are many examples of Ofcom's widespread use of the practice.

Use of technical cost modelling by other NRAs

Technical cost modelling has also been used to set fees for international renewals of mobile spectrum. New Zealand and Australia as quoted by DotEcon, have made extensive use of technical cost modelling.

DoteEcon in their report on international benchmarking that accompanies this consultation[8] observes that:

> *"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."*
>
> *"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."*

[7] We consider this point in more detail in Annex 8 of this response

[8] International benchmarking of 900MHz and 1800MHz spectrum value, a report for Ofcom by DotEcon September 2013

> *"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."*

The DotEcon study goes on to report that:

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

Clearly therefore it is not just Ofcom that finds cost modelling useful in obtaining spectrum values – no insurmountable difficulty is apparently being encountered on a general basis by regulators in the application of the method in regulatory decisions. This is in stark contrast with Ofcom's provisional view in the present consultation.

2. AIP and ALF approaches to spectrum valuation are in principle entirely consistent

Ofcom's cost-modelling based method for determination between alternative spectrum uses and for valuing spectrum in conditions of spectrum scarcity enshrined in its "SRSP: The revised Framework for Spectrum Pricing" statement in 2010 is entirely consistent with its approach in this Consultation. However in practice, the provisional fee that Ofcom has derived for mobile in the present consultation is very much different from the fee that Ofcom is proposing to set for DTT, even where that has been calculated in relation to the mobile use of DTT spectrum. This error is at significant odds with Ofcom's duties of efficient fee setting.

In order to balance the usage of spectrum between alternative long term uses, the relative value of spectrum for such different uses needs to be assessed on a consistent basis. Otherwise there is no appropriate method to identify the location of the boundaries between alternative uses[9], particularly where there is long-run competition for alternative use.

Ofcom has a general duty to set an appropriate annual licence fee for all spectrum – in that sense there is nothing special about 900/1800MHz. The only difference between the spectrum being considered in this Consultation and other spectrum is application of the Direction. However, the conceptual underpinnings of Ofcom's approach here and in respect of the "AIP" that applies to other spectrum bands is identical.

Ofcom's overall spectrum fee policy

Ofcom has declared in the SRSP spectrum fee review statement of December 2010 that as a general principle, where spectrum scarcity has been established, it will use a technical cost modelling based opportunity cost (or AIP) approach to setting the fees for such spectrum. Where spectrum scarcity is not established, then it will set fees at a level designed to recover the appropriate proportion of Ofcom's own costs that relate to the particular band in question.

In the SRSP (the AIP fee review) statement, December 2010 Ofcom stated:

> "*1.9 Having considered the comments we received at a series of stakeholder workshops, as well as the formal written responses, we have recognised that in the past, including in our consultation document, we have used the terms "spectrum value" and "opportunity cost" somewhat interchangeably. We have done this without necessarily always explaining what we mean by "value" as there are a number of ways in which this term can be interpreted.* **When discussing setting AIP fees to reflect the value of spectrum we have usually meant that these fees would be set at the price that would emerge in a well-functioning market[10].** *In a well-functioning market, the price of spectrum would be equal to the value of that spectrum in the next highest value use, rather than the value that the current user (for example, a company) might place on the spectrum. Given the possibility of continuing confusion about our meaning of the term "value" in the context of AIP fees we have redrafted our*

[9] I.e. to allocate the volume of spectrum between competing alternative uses
[10] Vodafone emphasis

> *AIP principles and methodologies to clarify that we set AIP fees on the basis of opportunity cost."*
>
> *"5.76 As we have said in the previous section one key aim of this pricing Framework is to set out clearly our principles of pricing and the methodology by which we set fees and thereby improve the transparency by which we set fees, including the type of evidence that we will use as the basis for our decisions.*
>
> *5.77 Evidence can include economic studies, whether commissioned by us or others. Where we commission external studies, including economic studies, we follow a procurement policy which is aimed to ensure fairness, transparency, value for money and adherence to Ofcom and EU procurement rules*
>
> *5.78 For economic studies specifically commissioned to inform our proposals for fee rates we expect to commission, frame and scope these on the basis of the principles and methodologies previously consulted on and concluded on in this Statement."*

Ofcom continues to apply this method in the setting of spectrum fees – for example in the upcoming review of the fixed point to point links spectrum bands in 2014[11] and in the fees review of the 470 - 700 MHz spectrum currently used for DTT. The Ofcom mobile data strategy document of November 2013 does however suggest that some or all of the latter spectrum may well be released to mobile use in due course.

SRSP and the current approach compared in principle

The underlying question that Ofcom is seeking to establish (i.e. the next most valuable use for spectrum outside the hands in which it is currently held) is the same in its SRSP approach as in the current consultation. 'Opportunity cost' is synonymous with 'market clearing price' and a simple comparison of Ofcom's description of its approach in the SRSP and the current consultation makes this readily apparent.

This approach in the SRSP in paragraph 1.9 quoted above, namely to reflect the value of spectrum that would emerge in a well-functioning market equal to the value of the next highest value user is identical to the conceptual framework Ofcom sets out at 2.8 of the current Consultation:

> *"We consider that full market value is the price that* ***would arise in a well-functioning spectrum market.*** *This would be the market clearing price when supply equals demand. …that remains our view and* ***is the basis upon which we have developed the proposals in this document."***[12]

In principle therefore, the two approaches should converge on the same outcome of market value.

Application of the SRSP: DTT

The very recent example of the use of opportunity cost modelling in fee setting is in the Ofcom assessment of the future of UHF 700MHz spectrum for DTT or for mobile use.

[11] As described in the Ofcom spectrum review update December 2012
[12] Current consultation at 2.8 and 2.9

But here there is a significant conflict that emerges with respect to the method of valuing mobile spectrum for annual fee setting. Ofcom's present intention from the spectrum pricing for terrestrial broadcasting consultation in March 2013 and statement in July 2013 is to use a technical cost model to derive the opportunity cost of mobile to determine the most effective use of 700MHz.

Ofcom in its statement on Spectrum pricing for terrestrial broadcasting, July 2013 said:

> "*2.7 As stated in the Consultation, we still consider at this stage that AIP is an appropriate pricing mechanism for spectrum use, and believe it will remain relevant in future. We will put forward our full reasoning and consider all relevant evidence at the time we make firm proposals on its introduction (i.e. nearer to 2020).*"

In effect however by comparison with the present consultation it would appear to be Ofcom's intention to charge DTT an annual spectrum fee based on mobile technical modelling, but to charge mobile an annual spectrum fee based purely on historic auction data. Although the underlying aim of establishing market value is the same in each case, the method Ofcom has employed in arriving at the market value of mobile spectrum is rather different. This raises a question of regulatory consistency that we discuss in Annex 1

Significantly, the two methods are very different in their outcome. From the mobile technical modelling in the DTT consultation, Ofcom has determined an indicative annual AIP charge from 2020 of £40m per multiplex, or £240m across 216MHz[13]. This amounts to £1.11m per MHz in 2020. However in the present 900/1800MHz consultation, by reference to historic auction values Ofcom has come up with a charge in 2013 prices of £1.99m per MHz of 900MHz. Since Ofcom expects to increase the mobile spectrum fee by inflation, the outcome could be (with 2.5% inflation) that in 2020 the mobile fee will have risen to £2.30m per MHz.

Clearly this is more than double the technical cost assessment of the value of mobile, and is also therefore more than double the sum that DTT operators are to be expected to pay for the full market value of mobile spectrum. Ofcom has made no attempt to examine, consider or reconcile this difference. This issue of inconsistency is made even more significant by Ofcom's view in the November 2013 mobile data strategy document that some or all of the 216MHz DTT spectrum could be released to mobile in due course. Parity of charging becomes even more important in these circumstances in order to ensure efficient use of the 470 – 700MHz spectrum. This gives rise to questions as to whether Ofcom has properly exercised its duty to ensure that spectrum is used efficiently, as we discuss in Annex 1.

Furthermore the two views of spectrum value are not prepared on a similar basis in terms of the recovery of a lump sum spectrum value across time. The Analysys Mason 700MHz method uses as a starting point the lump sum derived from a present value of a time series into perpetuity (using 20 years of data plus a terminal value) and then sets the annual recovery over the same extended period. By contrast the 900/1800MHz method attempts to recover the assessed lump sum of value over a 20 year period only. Were the Analysys Mason 700MHz method be adjusted to derive a lump sum suitable for recovery over a 20 year period i.e. to exclude the terminal value in deriving the lump sum and to recover fees over the same 20 year period then it

[13] DTT Fees consultation, March 2013 at paragraph 5.11

would produce a rather lower annual fee than £1.11m per MHz, exacerbating the difference between the DTT mobile approach and the present mobile approach.

Recent comments by Mr Vaizey[14] as well as by Ofcom make clear that Ofcom and Government consider that an AIP approach based upon cost modelling can and will achieve 'optimal use of spectrum' by sending appropriate pricing signals to ensure efficient use. We agree with Ofcom that the spectrum fee for the present DTT spectrum should be set on an AIP basis, using mobile technical cost modelling to identify the alternative use. We made these points to Ofcom in our response to the DTT spectrum fees consultation in 2013.

It follows also that if such a rate correctly sets an appropriate location of the boundary of use between mobile and DTT, then charging mobile any more than this rate is excessive, and not in line with Ofcom's general duties. We consider this point in more detail in the legal section of this response.

There is a very clear risk that an incorrectly set mobile annual licence fee, above an opportunity cost / market clearing price level will lead to inefficiently used spectrum – especially when the opportunity cost method is being used as the tool to determine alternative spectrum uses, as in the case of DTT.

[14] Ed Vaizey in a speech to the Digital TV group May 2013

3. Ofcom's rejection of technical modelling for 900/1800MHz spectrum is mistaken and inconsistent

Ofcom has not actually turned away from the use of technical modelling in the present context as a matter of principle: it has merely concluded[15] that it has good enough data from the UK auction and from international benchmarking to be able to disregard technical modelling given the (exaggerated) difficulties of the method.

> *"It is far from clear that generating additional estimates of spectrum value based on network cost modelling would allow us to reach a better-informed view, particularly because of the complexity of the modelling, the sensitivity of any such estimates to assumptions about the underlying parameters, and because the intrinsic value of spectrum may not be fully captured by such modelling, which typically focuses on the scope for reductions in infrastructure costs."*

We show elsewhere in our response that the data available from the auction/benchmarking methodology is not as strong as Ofcom suggests, and is clearly only in itself indirect observational data on the value of the 900MHz and 1800MHz un-auctioned spectrum. We have suggested that there are sound logical reasons as to why in the UK the value of 900MHz should be considerably less than that of the historic 800MHz auction value, but such reasons do not in themselves allow quantification of any such value discount. Given the materiality of the sums concerned in the present consultation, where Ofcom is contemplating the transfer out of the mobile industry of more than £300m every year, Ofcom should be taking as many approaches as are practical to attempt as rigorous a quantification as is possible.

Technical cost modelling does offer the opportunity for quantification of spectrum value. It should be emphasised that Ofcom's objections and concerns have not arisen from review of a model that has been written specifically for the present particular purpose. Rather Ofcom's criticisms appear to arise from observation of models that have been developed for different purposes and with different focus. Ofcom has quite simply failed even to attempt to build a model for the current purpose[16] – we see this as a significant error. In fact Analysys Mason have written for Ofcom, in relation to mobile use of the 700MHz spectrum, a model that would appear to have reasonable similarities to the model that is required in the current circumstances – whilst this model is not without some flaws, they are correctable. We consider the point below that in fact 700MHz is not a bad proxy for 900MHz, and thus the Analysys Mason model can provide useful insights into the value of 900MHz spectrum.

Clearly the output of any model will vary with the underlying parameters that are selected, but this should not stop Ofcom from attempting to identify a value range from the method. Ofcom in the SRSP statement has already considered the point on the sensitivity of the output to the inputs in any model, and concluded that there are ways round this potential issue:

> *"5.104 We recognise that with any estimation of spectrum value, by whatever method, there is always a risk that we get it wrong. This is particularly the case where we are dealing with uncertainties in any feasible alternative use. We address the specific issue of dealing with uncertainties under principle 9.*

[15] In the consultation in A6.26 and subsequent paragraphs
[16] Or adapt an existing model for the current purpose

> *5.105 On the issue that LCA modelling is sensitive to the input assumptions, we recognise that the LCA method requires us to make assumptions on the inputs used to calculate the opportunity cost of spectrum and that inevitably this means that there is a risk of error in our estimations. However, we believe that it is the best available method to estimate the price that would emerge in a well-functioning market. Additionally, we give the opportunity to stakeholders to comment on our specific fee proposals to mitigate the risk of erring when setting spectrum fees and improve the accuracy of our calculations."*
>
> *"Proposed principle 9: setting AIP fees to take account of uncertainty. Where there is uncertainty in our valuations and the likelihood of demand for feasible uses appearing we will consider the risks from setting fees too high, or too low, in light of the specific circumstances. When spectrum is tradable we will consider the extent to which trading is expected to promote optimal use, and will also have particular regard to the risk of undermining the development of secondary markets."*

Obviously therefore any issue with uncertainty is not a generally irremediable problem for Ofcom in setting other spectrum fees. It is not clear to Vodafone why it is presented as such an insurmountable problem with respect to 900/1800MHz mobile spectrum, particularly when in the case of the DTT modelling in 2013, Ofcom has been prepared to make recent use of it in assessing mobile spectrum value.

Given that the evidence from the UK auction and international benchmarking is nowhere as near as absolute and clear cut as Ofcom asserts, the imperative of using alternative methodologies of deriving value is clearly increased. At the very least technical cost modelling can be used to inform the view on the necessary degree of adjustment in the UK of the historic auction values of 800MHz and 2600MHz spectrum to derive a forward looking value of the non-auctioned spectrum.

There are two basic flaws with Ofcom's discussion and dismissal of cost modelling:

- Ofcom dismisses multiband spectrum modelling as too difficult when it has quite happily used it in other contexts;

- Ofcom dismisses technical cost modelling in general on the grounds that single band modelling for coverage is uncertain. However single band modelling is not what is required or appropriate in the context of the multi-band portfolios that all operators now hold, so any discussion of its difficulty is totally irrelevant in the present circumstances.

Ofcom's conclusions in relation to cost modelling therefore are wrong. Ofcom apparently considers two separate questions for network cost modelling, from paragraph A6.2:

- *"Whether it is appropriate to use network cost modelling to generate specific estimates of the absolute or relative value of spectrum in the context of revising ALF; and*

- *Whether, if it is not appropriate to do so, our interpretation of network cost modelling and other technical evidence can, nevertheless, inform us as to the ranking of bands (e.g. by indicating that one band has a higher value than another)."*

Ofcom then proceeds to report licence holders' views particularly of Vodafone of the need for technical cost modelling. It then considers some of the cost modelling that has been carried out to date:

- By Ofcom in the pre-auction spectrum liberalisation and competitor analysis, discussed elsewhere in Vodafone's response. The initial focus of much of this work related to the ability by band to provide a coverage network for LTE, but the issue of relative carrying capacity was also considered;

- The work already discussed by Analysis Mason for Ofcom on the mobile use of 700MHz spectrum – this was very much an evaluation of the ability of such incremental spectrum to support and enhance the supply of mobile services already being carried on the post-auction spectrum holdings of the operators. Ofcom also notes that Analysys Mason have been asked for further, follow-up work on this matter, so it cannot be considered to be an approach of no value by Ofcom;

- The review for Ofcom by DotEcon in 2013 of the use of technical cost modelling internationally;

- An exercise for H3G by Analysys Mason on the short-term advantage of 900MHz over 800MHz. But this exercise is not in the public domain, and Ofcom's description and criticism of it suggests a limited long term applicability.

Ofcom fails to consider other examples that we have listed above. In particular it appears to make no mention of the exercise commissioned by Ofcom in July 2012, where DotEcon and Aetha made use of cost modelling as an aid to setting auction reserve prices, i.e. employed not only international benchmarking but also cost modelling to obtain a view of spectrum value.

We consider separately below the issues of multi-frequency vs. single frequency modelling, and whether Ofcom's dismissal of single frequency modelling are relevant to the present context.

Multi-frequency vs. single frequency modelling

Having briefly listed cases where in the past technical cost modelling has been employed, Ofcom states in A6.16 "*since multi-frequency networks are very difficult to model, network cost modelling is often carried out for a single frequency network, so that it provides an estimate of the value of a spectrum band considered in isolation*."

It however provides no evidentiary grounds whatsoever for either part of this statement. In fact the Analysys Mason DTT model to which Ofcom refers is a multi-frequency model, and Ofcom would appear to have sufficient confidence in it to be able to use the model to derive an indicative prospective DTT spectrum fee. We note that in paragraph A 6.11 of the consultation Ofcom notes that it has "*recently commissioned Analysys Mason to conduct a further study on the value of 700MHz for mobile broadband building on Analysys Mason's previous work and other technical studies of relevance to this question*". Ofcom does not therefore consider the approach invalid or impossible. The Aetha 2012 model was also as multi-frequency model that Ofcom was quite happy to use in the spectrum auction reserve price setting exercise.

In simpler days, previous models such as those built by Ofcom and Vodafone in 2004 may have needed or been able to be single-frequency models, but that is no longer true, or in the least way relevant. Where operators possess multi-band spectrum portfolios, and mobile services can be supported on multiple spectrum bands, either independently or jointly, it is both impossible and incorrect to attempt to value a single band in isolation.

The overall problem is unchanged: at issue for the valuation of a particular incremental spectrum unit is the nature of the required network build that would be necessary in the absence of that spectrum (or avoided by the addition of a bit more). This at a high level is exactly the way the previous opportunity cost pricing measures have been derived for spectrum, such as the Ofcom/Vodafone models in 2004. However as we consider below, such an evaluation can only take place in the context of all the spectrum bands that a current mobile operator is able to employ, now and into the future.

The use of a particular spectrum band by a mobile operator can no longer be considered in isolation

In recent years any evaluation of the need for any particular spectrum band by mobile operators and hence its value has become considerably more complex, as operator choices of spectrum, device, technology etc. have widened. The original view of one spectrum band for one technology for one operator no longer applies.

The traditional picture of mobile traffic is that it is conveyed from the mobile device to a mobile radio access network, and from there into the mobile core network, and then to its destination. The mobile radio access network (or RAN) consists of a large number of radio base stations or cell sites, which are interlinked with the core with backhaul links. A cell site can be provided with radio equipment up to the limit allowed by the spectrum licences held by the operator. That equipment will, other things being equal, define the maximum carrying capacity of the cell site. The frequency of the spectrum being deployed will to some extent impact the area that the cell site can interact with, particularly where the density of traffic per unit of area is low.

Cell site density is in large part a reaction to traffic density – as the density of traffic rises, more cell sites are required to be able to continue to convey the total of traffic demanded, unless more spectrum can be made available. Each new cell site is a source of both a capex cost to build it and install all the necessary equipment, and an opex cost to continue to run it.

Spectrum cost modelling is aimed at this particular network cost point – if it is assumed that the supply of spectrum were to be variable, what might be the present value of the incremental cell site expenditure that results from any change in the supply of spectrum? From this a value of the spectrum increment can be derived.

In prior years, where the mobile services demanded have been confined to voice and text, and where the supply of spectrum has been more or less static, the position for a mobile operator in the face of rising traffic demands has been quite straightforward – in areas where the supply of traffic carrying capacity is insufficient to meet the demand more traffic, the only recourse is more cell site construction. Furthermore the position existed that more traffic would lead to more revenue, so the provision of additional capacity might be expected to be able to be made profitably.

The situation today, however, is a little more complex, but by no means impossible to model. It is no longer possible to value any particular band in isolation - a broader range of factors need to be considered:

- Multiple mobile technologies 2G, 3G and 4G – these continue to vary in terms of the spectrum band that they can use.

- Multi-band, multi-technology spectrum holdings by the operators;

- Little or no licence limitations on use by spectrum band;

- Devices are multi-technology and multi-band capable (and also backwards compatible in terms of technology although with a preference for the most efficient technology available).

- Demand growth is for data rather than voice or text, both of which are no longer exhibiting a strong upward growth trend – 4G/LTE is the best technology for conveying data (and the one that has been optimised for it).

- The demand for data through mobile capable devices can also be satisfied at least in part by alternative means other than traditional macrocells, especially wi-fi offload and small cells (where mobile is not available or in the alternative where such offload can provide a superior service).

- The volume of demand is rising significantly, but not the revenue, putting at risk the affordability to the operator of capacity expansion. However the benefit from data to the user may be relatively linear to volume i.e. the user extracts more value from additional data traffic than the operator obtains in revenue.

- Continuing technological improvements provide the opportunity for very significant future increases in the capacity/throughput per unit of spectrum.

- The volume of available spectrum is also set to rise significantly with major initiatives to release additional spectrum for mobile use as evidenced by the recent road map provided by the Ofcom mobile data strategy document in November 2013.

In this slightly more complex world, the value of a particular unit of spectrum to an operator is therefore rather more nuanced than in the past. Any evaluation needs to be made in the context of all these variables, to consider what the impact on the operator of an increase or decrease of that particular unit of spectrum might be. The problem is not at all incapable of resolution – indeed Ofcom has made broad strides in this direction in its evaluation of the benefits of mobile use of 700MHz in its DTT alternative use modelling in March 2013. As we consider below, this evaluation did in fact give a relatively low value per MHz of such incremental spectrum on a 20 year equivalent lump sum basis.

But the existence of these multiple varied factors also suggests, as we consider in more detail in Annex 8, that the long run value of incremental spectrum is very likely to fall given the wide range of substitutional spectrum and technical solutions available and likely to be available in the future to operators.

Ofcom's criticisms of single-frequency modelling are irrelevant and in any case are not unsolvable

Despite the need in the present context of multi-band operator portfolios for multiband modelling, Ofcom's criticisms of the difficulties of modelling are then mistakenly pointed solely at single frequency modelling, in the assumption that the operator only has access to one band or that only one band is relevant for modelling and valuation purposes. The main criticism then made by Ofcom relates to the wide variation of the estimates on the number of sites required for coverage for a single particular band, but as discussed this is fundamentally irrelevant in the present circumstances.

In A6.14 Ofcom notes in some detail that the DotEcon international benchmarking study September 2013 apparently noted considerable differences of opinion on:

- Cell radii;
- Cell areas;
- The number of sites required for coverage

These are presented by Ofcom as if they were separate and independent problems – this however is potentially misleading. In reality these are not three separate problems, but differently expressed characterisations of exactly the same issue. The coverage of an individual cell can either be expressed as an area that can be expected to receive coverage, or as a maximum or average cell radius of coverage. Both are metrics that seek to describe the coverage ability of an individual site. The number of sites required for coverage over a wider area is obviously dependant on the size of that area and the individual coverage ability of each site. Therefore this is not a catalogue of multiple problems, but merely the same problem mentioned three times in a slightly different way.

Ofcom then raises the objection in A6.19 onwards that the output is dependant on uncertain assumptions, particularly of demand. This is obviously true, but this uncertainty has not stopped Ofcom from for example building in other contexts very complex charge control models based on forward looking assumptions that are also highly sensitive to their demand (and other) inputs[17]. Furthermore Ofcom then mistakenly characterises the demand uncertainty solely in terms of the number of coverage sites that are required by a single band:

> *"The consultation on spectrum liberalisation mentioned above estimated the additional sites required in densely populated areas to achieve a certain performance level, using only UMTS 2100 (rather than also deploying UMTS 900). As Figure A6.1 below shows, the model found that the results varied greatly depending on demand assumptions, ranging at the extremes from 5,700 sites in a "lower demand" scenario (8,600 minus 2,900) to 13,800 (21,100 minus 7,300) in a "higher demand" scenario."*[18]

Figures A6.2 "additional costs for an operator using only UMTS2100 compared to an operator deploying UMTS900 (assuming the same service is provided" and A6.3

[17] In fact examination of the sensitivities of a model can prove beneficial in assisting in model calibration and impact analysis

[18] Consultation at paragraph A6.21

"coverage performance (based on 12,000 sites) by band and service level" make exactly the same point.

But Ofcom is again tilting somewhat repetitively at entirely the wrong windmill. We can accept that the coverage uncertainty can cause difficulties for a model of that sort i.e. one that is designed to address the question of how many coverage sites are required for a particular band, but in the present context this is not the relevant problem at all. Also in any event any such difficulties did not stop Ofcom from using the information it obtained on relative coverage ability of spectrum bands in its reserve price setting for the auction and for determining the auction rules particularly around the competitor analysis.

Furthermore it is quite obvious that the MTR model employed by Ofcom (and prior to that by Oftel) that has since 2002 been used to establish a mobile termination charge control is based in part on a decision that Ofcom has taken on the size of the network in terms of the number of sites that is required by the average efficient operator to establish a coverage network. Ofcom in fact in the past modelled different specific coverage network site builds that it believed were required for coverage networks at different spectrum frequencies. Clearly any issues with the number of sites required for coverage cannot thus be seen to be an insurmountable regulatory problem for Ofcom.

The advantages of a multi-band model

In fact, the use of a multi-band model is simpler and more effective than a single band model since it largely or entirely bypasses the coverage sites problem – which can be made virtually a non-issue in the model. The issue of coverage site numbers is irrelevant to the valuation of incremental spectrum fundamentally because all mobile operators have coverage networks already and are planning to roll out a very significant number of sites in the next few years – a typical expectation is of at least 18,000 sites. The value of incremental spectrum is thus relates primarily to the ability to increase the traffic capacity (where necessary) at these sites versus the alternative scenario of requiring additional site build above the 18,000 base number in order to increase traffic carrying capacity, in areas of dense traffic demand.

Ofcom is not unaware of these site numbers of 18,000 or so: in its report "the availability of communications services in the UK, May 2013" it notes in paragraph 5.53:

> *"There are currently two separate agreements in place between mobile operators to share transmission sites in the UK. EE (created following the merger of T-Mobile and Orange) and H3G currently share around 18,000 sites, which are now undergoing a modernisation programme. O2 and Vodafone have also recently announced plans to consolidate their network infrastructure into a single infrastructure network, which should total around 18,500 sites. These developments could lead to a significant improvement in mobile coverage and quality over the next few years, particularly in less populated areas where there may currently be a more limited choice of provider."*

The value of additional or decremental spectrum needs to be considered in the context of the pre-existing coverage network, as the Analysys Mason DTT model does. Analysys Mason report on page 79 of their March 2013 document:

> "*our calculations of network cost savings are based on an assessment of the number of sites which the modelled generic operator could avoid building if more spectrum (in the 700MHz band) were to be made available to it.*"

This model used in its central case a starting number of 17,500 sites – this number is clearly in the right ballpark for the evaluation, although a little on the low side[19].

The model that Ofcom supplied with the mobile data strategy consultation in November 2013 also used as a starting point 18,000 deployed sites for the typical mobile operator[20]. Discussion therefore of significantly smaller minimum coverage deployments is not relevant in the present context.

The real modelling issue that needs to be addressed is: given that all MNOs are going to build a large number of sites for LTE in the next few years (by around 2015 - 2017), what the impact of additional/decremental spectrum will be (at different bands), in terms of network cost avoided. This is exactly the same principle as the Indepen/Vodafone opportunity cost models from 2004, which considered the value of the incremental/decremental spectrum to be related entirely to the traffic carrying capacity of mobile sites, and nothing to do with relative coverage ability.

This method requires a two scenario approach: when the difference between the two modelled scenarios is purely an amount of spectrum, what are the differential network costs? But this differential needs to be measured against a network that already has 18,000 or more sites installed – any comparison of required build against any lesser number of sites for coverage is irrelevant when that coverage and the overall levels of site numbers have both already been established.

We are not suggesting (unlike Indepen in 2004) that in this 900MHz and 1800MHz are identical in any such modelling. The frequency of the band under consideration is still to some extent relevant in its ability to provide usable capacity, but this applies to a much less significant degree than when the evaluation is being made purely for coverage purposes. As we discuss in more detail in Annex 8, as the Ofcom mobile data strategy consultation notes, there may still be some differences between the bands with respect to effective spectral efficiency where the spectrum is being added for capacity, rather than for coverage. However this difference reduces as the area covered by a site contracts.

Ofcom in the present consultation has ignored its own body of work on the relative ability of mobile spectrum by bandwidth to increase capacity. The mobile data strategy document provides a useful and usable summary of Ofcom's considerable work on this point, work that was largely conducted as part of the review process that led to the recent auction. This information base can be used for the purposes of modelling relative spectrum value.

The use of an incremental modelling approach

Furthermore, this required two scenario model approach is very similar in high level principle to that recently employed by Ofcom in the MTR charge control to derive a

[19] The effect of this will be to tend to overstate the network build costs output from the model and thus overstate the value of spectrum

[20] But then assumed a further, small continued build, apparently independent of demand forecasting

LRIC of termination. The object in both cases is to measure the differential network build when different/subtractional input assumptions are used. In the MTR charge control the difference between the two modelled scenarios is a change in traffic volumes through the removal of termination traffic: as a result the network build costs go down when terminated traffic is removed. This reduction in network cost is then used to calculate the LRIC of termination by comparison with the volume of traffic that has been removed. In mobile spectrum modelling the difference between two scenarios is the volume of available spectrum that is used by the network operator. Here the network build costs go up when spectrum is removed – but again it is the change in costs that results from the change in input values between the two scenarios that is of importance.

In the wholesale MTR charge control process, Ofcom has expended very considerable effort in developing a large and very complex model suitable for setting inter-operator transfers of value for a charge control period of four years – such a model, despite the very considerable uncertainty on its inputs, has been used by Ofcom to determine the single rate to be set in each year. By contrast Ofcom has failed to build a spectrum model in the case of 900/1800MHz spectrum, in circumstances where Ofcom is contemplating an outflow from the industry in excess of £300m per year for a very considerable number of years.

Like the MTR model, the DTT model built for Ofcom by Analysys Mason is also incremental in nature – it considered the position of what would be the advantage to a given operator with a multiband portfolio of existing spectrum (including that acquired in the 2013 auction), of some additional 700MHz spectrum. This model is very much simpler in conception and execution than the MTR model[21]. In the model with extra spectrum the network build costs go down, and the present value of the reduction in costs can be viewed as the value of the incremental spectrum. It is however, without any model modification, perfectly possible to recast the order of the model's output scenarios and consider the base scenario to be the network build costs when all possible 700MHz spectrum is used by the operator, and then compare it with the higher network build costs in a scenario with slightly less 700MHz spectrum (as a proxy for slightly less 900MHz spectrum). In other words its outputs can also be interpreted in the decremental manner necessary for valuation of spectrum in use. We consider this approach and its results below.

[21] The DTT model is one workbook of less than 1MB, whereas the MTR model consists of seven integrated workbooks totalling over 35MB

4. The Analysys Mason DTT model

The Analysys Mason DTT model gets relatively close to becoming a meaningful model of technical cost modelling that could provide a valuation of 900/1800MHz spectrum, but because of its somewhat different purpose, it does not quite yield fully usable data. However the model does give, when its outputs are interpreted properly, a low spectrum value for incremental sub1GHz spectrum - £2.2m per MHz for the most marginal 2*5MHz carrier, and an average of £9m per MHz across a 2*15MHz reduction of spectrum. It is possible to view these outputs for 700MHz to be a reasonable proxy for the long-run value of 900MHz spectrum.

In fact, it can be considered that 700MHz is in practice a reasonable proxy for 900MHz, and one that is potentially superior to 800MHz. As we have established in annex 8, 800MHz is being used by mobile operators to launch LTE services and supply a basic coverage layer. Subsequent additions of spectrum will serve to provide additional capacity, rather than coverage. In this respect both 700MHz and 900MHz are likely to perform a similar function for LTE[22]. Thus their forward looking long run values are likely to be similar.

As we discussed earlier, the Analysys Mason DTT model attempts to consider the value of 700MHz spectrum to a mobile operator, assuming a given future release date and a given quantity of 700MHz spectrum. It is in effect an incremental model, in that its starting base scenario is of a typical operator post-auction spectrum portfolio (with of course no 700MHz spectrum), and it then considers alternative scenarios where a quantity of 700MHz has been added to the portfolio. In all scenarios the model calculates the radio access network expenditure that is required to address the forecast volume of traffic in each year, in terms of both capex and opex[23]. In general the model shows that the more spectrum that is available to the operator, the lower is the resulting network expenditure. The total cost for each scenario is then converted into a present value (utilising a terminal value for costs beyond the formally modelled period, i.e. after 2035). The difference in the present value of total cost between two scenarios, i.e. between the base scenario and a particular alternative can then be derived.

The model however includes no additional spectrum across the whole modelled period to 2035 beyond the immediate post-auction holdings and 700MHz: this is clearly no longer correct, given the road map of release of substantial additional mobile spectrum that is planned in the Ofcom mobile data strategy consultation, as we discuss in more detail in Annex 8 of Vodafone's response. Other things being equal therefore, the model is thus likely to overvalue the spectrum that it does include.

Outline structure of the model

The basic methodology of the model however would appear sound. As described in page 80 of the Analysys Mason report:

> "*Our model calculates the total mobile network traffic and the distribution of traffic per site, and compares this to a calculation of the total capacity per site. This approach enables a calculation of exactly how many new sites are needed,*

[22] Although Ofcom's mobile data strategy document does suggest that 700MHz is likely to become available for LTE before 900MHz is fully refarmed

[23] Over and above the pre-existing 17,500 sites

given the generic operator's existing spectrum portfolio and how many could be avoided given access to different amounts of 700MHz spectrum."

In order to calculate this required network infrastructure requirement under both scenarios, the model takes into account:

- o *"The total number of sites in operation*
- o *The total busy hour traffic on the network*
- o *The distribution of that traffic between geotypes and across the sites within each geotype*
- o *The capacity per site with and without 700MHz spectrum*
- o *The capacity boost offered by additional 700MHz spectrum*[24]"

On page 86 of the report, Analysys Mason describes the outputs from the model:

"W*e are calculating a per MHz opportunity cost of the spectrum, so the amount of 700MHz spectrum held is only significant to the extent that the per MHz technical value changes. However we find that this per MHz value can vary quite significantly because for each incremental 2*5MHz lot of spectrum that is added to the generic operator's portfolio, the number of new build sites avoided decreases. In other words, 2*10MHz of spectrum reduces the number of new site builds required by less than twice the reduction brought about by 2*5MHz of new spectrum. This means that 2*10MHz is not worth as much as double 2*5 MHz of spectrum from a network cost saving perspective and is therefore worth less on a per MHz basis*".

This is entirely expected – as we describe in section 2 of our review of the relative value of 900MHz and 800MHz in Annex 8, each successive increment avoids a smaller (and later) network cost and thus has a progressively lower value than its predecessors.

What the model finds is described in figure 5.15 of the report (in relation to its central scenario output): the value of the increment of 2*5 MHz is £378m, of 2*10MHz is £539m, and of 2*15MHz is £606m. Or to put it another way, the value of the first 2*5MHz is £378m, of the second 2*5MHz is £161m, and of the third is £67m.

Figure 5.15: Value of 700MHz spectrum [Source: Analysys Mason, 2012]

	2×5MHz	2×10MHz	2×15MHz
Full value (GBP million)	378	539	606
Annualised value (GBP million/MHz)	2.21	1.58	1.18

These values are extracted by comparison with the null scenario of having no 700MHz spectrum. The model outputs that give rise to the table above are actually:

- Present value of incremental build costs with no 700MHz = £833m
- Present value of incremental build costs with 2*5MHz of 700MHz = £455m i.e. a saving of £378m, as above

[24] Page 81 of the report

- Present value of incremental build costs with 2*10MHz of 700MHz = £294m i.e. a saving of £539m

- Present value of incremental build costs with 2*15MHz of 700MHz = £228m i.e. a saving of £605m

Clearly this is the correct way to consider 700MHz on an alternative use basis, where at issue is the value that mobile could make of a given incremental volume of spectrum. But in the present consultation, at issue is the value not of future prospective spectrum, but of existing mobile spectrum currently in use by mobile operators.

Vodafone's interpretation of the outputs of the Analysys Mason model

To Vodafone the requirement of the current consultation drives another way of looking at these outputs. One can assume that 700MHz can stand to some extent as a proxy for 900MHz (in that the position to be considered is that the average efficient operator has to the year 2034 a portfolio that includes 700MHz), and that at issue is the value the operator might ascribe to having or not having an increment of 900MHz spectrum. On this basis we can see from the model outputs above[25] that with an assumed operator spectrum holding of 2*15MHz of 700MHz (a rough equivalent to the paired 17.5MHz held by Vodafone and Telefonica), the present value of incremental build costs is £228m. This can then become the base case.

- However if one removes one 2*5MHz carrier (of 700MHz, but we assume the impact of removing a carrier of 900MHz would be similar), the present value of incremental build costs rises to £294m – in other words the extra network build cost arising from a reduction of 2*5MHz of the sub 1GHz spectrum is £294m minus £228m or £66m.

- If one removes a second carrier, the present value of the incremental build rises to £455m, an extra cost of £455m minus £294m or £161m.

- Removing the third carrier, the present value rises to £833m, an extra cost of £833m minus £455m, or £378m.

This quite clearly follows the obvious point discussed elsewhere in this document that the least value is supplied by the last increment of spectrum, and as progressively more spectrum is assumed to be removed, the incremental cost rises.

The other point that can be noted from the model data is that these values given above are assessed, as Analysys Mason makes clear, from a basis of modelled network build costs up to 2034 plus a terminal value after that. The use of a terminal value in the alternative long run use evaluation of DTT vs. mobile would appear totally reasonable.

This however is not the approach adopted in the present 900/1800MHz annual spectrum fee consultation, where in the Ofcom base case the value that Ofcom ascribes to 900MHz, of £25m per MHz is one that relates to, and is to be recovered over only 20 years, rather than in perpetuity. A recovery over an infinite period as

[25] When considered in a reverse, or decremental order

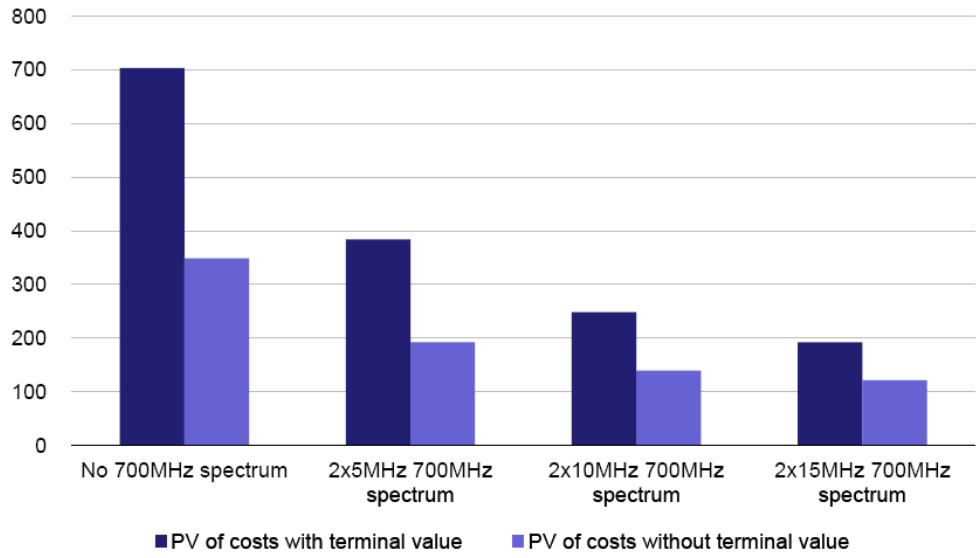
implied by the inclusion of a terminal cost value would obviously require a matching terminal recovery value, and would as a result give a year 1 recovery significantly less than that currently computed by Ofcom. Mirroring the current Ofcom methodology of conversion of the present value to an annual recovery over no more than 20 years would clearly require the terminal value of incremental cost to be removed from the Analysys Mason model's outputs in computing the present value of the incremental build costs.

This is an adjustment that was also made by DotEcon and Aetha in 2012 – in their July 2012 document they say at paragraph 161 in relation to the use of modelling to derive a lump sum value that:

> *"In the case of the licences to be awarded by Ofcom, the licences are of indefinite duration, but with an initial licence period of 20 years during which time no annual fees for the spectrum are payable and the reasons for varying or revoking the licence do not include spectrum management reasons. Following the initial 20 year licence period, Ofcom is able to charge annual fees for the use of the spectrum and is also able to vary or to revoke the licence for spectrum management reasons. In view of this we undertake our assessment of the value of the licence by modelling the incremental cash flows over the initial 20 year period of the licence and do not include a 'terminal value' assessment of the value beyond this period."*

This adjustment to the Analysys Mason model is straightforward, since the scenario analysis in fact supplies outputs both with and without a terminal value as figure 5.14 below shows.

Figure 5.14: NPV of different spectrum holding scenarios in the base case [Source: Analysys Mason, 2012]



It can be readily seen that a considerable proportion of the full present value comes from the terminal value calculated for beyond 2035. This is hardly surprising given the expectation of rising traffic demand in every year up to 2035. The basic data without the terminal value is as follows:

- No 700MHz spectrum = a present value of incremental build costs of £413m;
- Adding 2*5MHz = a present value of £226m build costs;
- Adding 2*10MHz = a present value of £166m build costs;
- Adding 2*15MHz = a present value of £144m build costs.

If we employ these present values in the subtractional manner more relevant to the present consultation, and start from a multi-band operator spectrum portfolio that includes all 2*15MHz of 700MHz spectrum, then the base case is a present value of £144m. Removing one carrier would increase costs by £22m (£166m - £144m), removing the second would further increase costs by £60m (£226m - £166m), and removing the third would increase costs by £187m (£413m - £226m).

To the extent that this simple exercise gives a representative view of the model's outputs suitable for use as a proxy for 900MHz valuation, then the present value of the 20 year view of costs avoided from the model would be £2.2m per MHz for the first carrier removed, £6m for the next, and £18.7m for the last, with an average across all 3 carriers of £9m[26]. This is considerably below the spectrum values that Ofcom has generated from the UK auction – but it may be a reasonable representation of the necessary discount between 800MHz auctioned spectrum and 900MHz spectrum post-auction. Or in the alternative it strengthens the view that if the value discount observed in the international auctions is to be applied in the UK, the percentage that should be adopted is one that gives a 900MHz value at the bottom end of the range, i.e. at £12m based on Vodafone's calculations elsewhere in our response.

Flaws in the Analysys Mason model

Whilst it is a useful indicator of the value of a technical modelling approach, there are some flaws in the Analysys Mason model that limit its usefulness for determining the value of 900MHz and 1800MHz spectrum, apart from the obvious point that the model was not built for that specific purpose. We briefly list three of them below.

Firstly there is an assumption made in the model that a proportion of mobile traffic in all cell site areas is traffic that quite simply cannot be handled by any other than sub1GHz spectrum. In its base case the model assumes that 30% of all mobile traffic could only be handled by such spectrum. This represents a gross over-simplification of the way LTE traffic can be handled by a multi-band operator, with wi-fi offload, small cells, load balancing and so forth, in the manner described in the Ofcom's mobile data strategy consultation. The result of this erroneous 30% traffic reservation is an overvaluation of the significance of sub1Ghz spectrum. Telefonica, in its response to the DTT consultation, May 2013 stated:

> *"Those familiar with the topic will recall that many important policy proposals have been made in the past regarding sub-1GHz spectrum (2G liberalisation in 2007 and 2009, Ofcom's auction proposals in 2006, 2011 and 2012). In the*

[26] (£413m - £144m) divided by 2*15MHz

> *end, each of these consultation processes has had to conclude that the benefits of sub-1GHz spectrum are marginal.*
>
> *"The extent of the improved quality of coverage is relatively small. The extent of this advantage will be dependent on the construction of buildings and the location of the user within the building. Little or no advantage would exist in many easier to serve indoor locations."*
>
> *Telefónica were therefore surprised, again, to see another document present sub-1GHz spectrum as having superior qualities to other spectrum, in the context of capacity constrained urban networks. In its report Analysys Mason asserts that deploying 700MHz on existing network grids will increase network coverage and mean that an additional 30% of traffic previously out of reach to supra-1GHz spectrum would be carried on the 700MHz layer. This assumption is clearly misguided.*
>
> *Ofcom's previous analysis showed that existing networks are now capacity limited, not coverage limited. Adding another spectrum layer increases the amount of traffic that can be carried, but not the effective size of the cell in areas where cell grids are dense.*
>
> *Furthermore, Analysys Mason's assumptions imply that MNOs do not undertake simple traffic management in their networks to improve performance for all users (not just those on 700MHz compliant devices). In its model Analysys Mason assumes that only 700MHz compliant devices will benefit from the deployment of 700MHz in networks.*
>
> *In reality MNOs will manage networks in a way that delivers benefits for all users. In this instance, 700MHz compliant devices would be forced into the 700MHz layer, thereby removing their traffic from other layers and improving speeds for all users.*
>
> *Correcting for these two issues allows us to conclude that the calculation of opportunity costs relates to areas of capacity constraint, not coverage limitation.*

Vodafone agrees with these points. To the extent that there is a disadvantage of >1GHz spectrum against sub1GHz spectrum it is not the absolute one described in the Analysys Mason model, such that 30% of the traffic can only be carried by sub1GHz spectrum. Rather there may be some lower ability of higher frequency spectrum for capacity in terms of effective throughput per MHz per unit of area, but this is not an absolute limit that cannot be overcome with some degree of additional macrocell site construction, additional active small cell offload, load balancing etc. Annex 7 of the Ofcom mobile data strategy document provides Ofcom's view of this comparatively small relative disadvantage – we consider this elsewhere in our response [ref].

Secondly the model provides no additional spectrum to mobile operators in the period to 2035 over and above the 700MHz spectrum despite assuming a very considerable increase in traffic volume. This lack of additional spectrum is an assumption that is clearly now out of date as a result of the mobile data strategy consultation document, which provides a roadmap for the release of substantial additional spectrum, some of which, on top of the 700MHz spectrum, will be available to mobile operators before 900MHz is usable for LTE. Introducing additional spectrum into the model will reduce the extent of the incremental network build that is required under rising traffic levels.

Thirdly the radio access network costs appear to ignore the possibility of network sharing between two operators. The unit costs adopted appear to assume that each network operator bears 100% of the costs of each cell site, unlike the MTR model which assumed that most macrosites would be shared between two operators. The network costs must therefore be considered to be an overestimate.

The conclusion from Vodafone's brief review of the Analysys Mason model was that whilst it was reasonable in general approach, in detail it was not correct and would need amendment for the purpose of setting fees for DTT in due course[27]. The model obviously does not attempt to value 900MHz spectrum, so only on a proxy basis can its outputs with respect to 700MHz be applied to 900MHz instead. The outputs when applied to 700MHz, to show an incremental cost per MHz of less than £10m per MHz even with a 2*15MHz increment, are a useful, but high indicator of the likely value of 900MHz spectrum.

Whilst Vodafone was not given access to the model to run different scenarios[28] and we could only observe the output of the base scenario, there were a couple of other useful insights that the model provided into the likely value of 900MHz spectrum:

- The required build difference between the base scenario with no extra spectrum and the additional 700MHz scenario emerges towards the end of the modelled period, i.e. the last increments of spectrum are principally required in the time of most traffic uncertainty.
    - So in the only scenario that we can see, of 2*10MHz of incremental spectrum, the model suggests a need for 159 additional sites by 2020, 501 by 2025, 735 by 2030, and 1,027 by 2034 – i.e. a large proportion of the additional builds are required towards the end of the period.
- This also means that a lot of the value when the outputs are considered on an indefinite period basis is in the terminal value, but the terminal value in Ofcom's method of lump sum to annual fee conversion is not relevant in the present context.
- Obviously the result must be strongly impacted by the traffic forecast and particularly the forecast in the last few years of the model. We were unable to test the sensitivity of this however.

The existence of the Analysys Mason model demonstrates that it is possible to build a model to identify the cost avoided by a particular unit of spectrum. However the different purpose of this model from the present issue, and our inability to access it to modify it or to run scenarios proved to be substantial obstacles to its full applicability for the assessment of 900/1800MHz spectrum value. We were surprised that Ofcom did not provide a similar technical cost model for the current consultation, and consider the absence of such a model a major defect of the consultation.

[27] Vodafone's response to Ofcom's consultation "Spectrum pricing for terrestrial broadcasting" May 2013. At page 1:
"However the modelling of the alternative use of 700MHz, whilst it is fit for the purpose of emphatically determining that it is mobile rather than DTT which has the higher value in use, is not (yet) sufficiently robust or reliable to establish any absolute value in use of mobile, since it appears to considerably overstate such value".

[28] For reasons discussed in the Vodafone response to the DTT spectrum fee consultation

But in fact none of the problems we have noted with the Analysys Mason DTT model are un-correctable - it is very possible that rather than starting from scratch, much of the existing Analysys Mason model could be used as the foundations of a model specifically aimed at valuing 900MHz spectrum.

In the next section we lay out what we consider to be the basic building blocks of such a model.

5. ***The design of an appropriate technical model to give a view on the value of 900/1800MHz spectrum***

In the absence of a specific Ofcom produced technical cost based model that is capable of supplying a value of incremental spectrum we have considered what in principle such a model would need to consist of. Such a technical model of spectrum value is relatively straightforward, requiring relatively few key elements. Initial values of many of the inputs and parameters are potentially already in Ofcom's hands, although some specific data might need to be sought from mobile operators. In essence the model would need:

- A forecast of future demand:
    - This forecast should be built up as far as possible on a bottom up basis, i.e. by using separate forecasts of penetration and usage by device type, rather than a top down approach that merely extrapolates current CAGR predictions of total network data traffic growth with no solid evidentiary underpinning. Ideally both top down and bottom up approaches should be employed and one used to calibrate the other in order to derive several different views of what is clearly a relatively uncertain outcome.
    - Ofcom already has several such forecasts in embryonic form, in the studies it has commissioned on the need for additional spectrum for mobile in the face of alternative forecasts of traffic growth, and in the Analysys Mason DTT model, which also uses a set of forecasts.
    - The forecast should allow for wi-fi offload, the use of small cells, an asymmetry of download to upload traffic, and other significant traffic variables.
- An assessment of how traffic demand is distributed, both across time (calculating peak or busy hour traffic from annual or monthly forecasts) and geographically (calculating predicted peak traffic loads per site)
    - The year to busy hour ratio can be readily adopted from such sources as the MTR model.
    - The distribution of traffic across the population of sites could be derived from the curve fitting approach of the DTT model, or from a real distribution of traffic specific to the UK operators e.g. on a percentile basis with a non-homogenisation assumption for each percentile.
- A forecast of future traffic carrying capacity at a site, based on:
    - future spectrum availability for download (including new spectrum and re-farmed spectrum);
    - future spectral efficiency in terms of the increasing effective carrying capacity per MHz of spectrum per unit area;
    - effective carrying capacity per unit per different spectrum band.

This could most likely take into account the work that Ofcom has already done on these input variables (for example allowing for the capacity carrying ability of each spectrum band from figure 18 of annex 7 of the mobile data strategy document), and Ofcom's various initiatives on releasing new mobile spectrum, the ability of wi-fi offloading and small cells to carry traffic load and so forth. The mobile data strategy document clearly provides a good summary of Ofcom's current best view of these variables to 2030 and beyond. We discuss many of these inputs in Annex 8 of the current response.

- From these inputs, a calculation of how many additional sites on top of the base rollout of 18,000[29] sites are required in each year to match geographically distributed peak traffic demand and site capacity. The output should be calculated twice, once with and once without a particular unit of incremental spectrum.
    - The difference in sites required each year between the two outputs, of the base scenario and a counterfactual (of less/more available spectrum than the base) should be calculated.
- A cost module that converts these incremental site quantities into capex and opex in each year (using assumptions of unit cost per year) and then into an incremental present value per MHz of incremental spectrum (both with and without a terminal value).

Clearly these final two steps could be run in either order.

We would expect that such a model, when properly constructed would give a lower value of 900MHz spectrum than that indicated by the Analysys Mason model for sub1GHz spectrum. We can be confident that any properly constructed model would, other things being equal, generate values no higher than those calculated in the Analysys Mason DTT model, i.e. below £9m per MHz for 900MHz. We are very clear that such a model would not generate a value of 900MHz spectrum (or for that matter 1800MHz spectrum) anything like as high as that currently estimated by Ofcom, except in a totally unrealistic assumed outcome of very high future traffic volume and very low future spectrum supply.

The position that Ofcom has taken however in the mobile data strategy document is that in order to avoid any "capacity crunch" where demand for mobile data is growing faster than the possible capacity supply, Ofcom is planning as we discuss in annex 8 to release a very considerable volume of additional spectrum in advance of such demand. Whilst in detail precisely what will be made available for mobile use and when each specific release will happen is obviously not certain, the direction of travel indicated in the mobile data strategy document is very clear. For the purpose of cost modelling it would be reasonable therefore to link together a high data demand forecast only with a high spectrum release forecast.

Certainly a scenario with a high data demand but no or very little additional spectrum should be discarded from modelling consideration. Given that this outcome is one that Ofcom is taking extensive steps to avoid, particularly through the release of additional spectrum to minimise any risks of a "capacity crunch" it would require a wholly

[29] Or whatever similar number is deemed appropriate

unjustifiable assumption of regulatory failure for such an outcome to feature in any sensitivity analysis.

In summary therefore the absence of a cost model for valuing 900MHz spectrum is a major omission. Based on the evidence of the Analysys Mason model, a properly constructed cost model would yield a value of 900MHz spectrum below the level currently shown by our analysis of the auction data of £12m to £15.9m. This suggests that if the auction methodology continues to be used as the sole approach, then the value of 900MHz to be adopted should at most be £12m, but the existence of a cost model would supply more comfort on the appropriate range of a reasonable 900MHz valuation that encourages efficient spectrum use.