frontier economics

SETTING ANNUAL LICENCE FEES FOR 3.4 AND 3.6 GHZ SPECTRUM

A report prepared for Three UK

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Confidential

CONTENTS

EXECUTIVE SUMMARY

Ofcom is consulting on the level of Annual Licence Fee (ALF) that should apply to Three's 3.4GHz and 3.6GHz spectrum (acquired as a result of Three's purchase of UK Broadband). In particular, Ofcom is focusing on how to take into account the information from the 2018 auction, where similar spectrum was sold. It considers two approaches:

1. Setting the ALF based on the market clearing price from the 2018 auction (£37.8m per 5MHz); or
2. Setting the ALF based on the marginal opportunity cost to other users - Telefonica's highest losing bid (£31.1m per 5MHz).

Three has commissioned Frontier Economics to review Ofcom's proposal and to assess whether it is likely to achieve an efficient outcome, i.e. to ensure that the spectrum is put to the most productive use and that consumer benefits are maximised.

Ofcom's position

Ofcom's key objective with regards to spectrum pricing is to ensure that spectrum is used efficiently and the benefits to society from its use are maximised. In the "Strategic Review of Spectrum Pricing" (SRSP), Ofcom states that:

"*benefits to society will be maximised over time if spectrum is priced to reflect opportunity cost. The opportunity cost is the price that would emerge in a well functioning market and reflects the value of spectrum to the best alternative use or user that is denied access to it*." [1]

Ofcom notes that typically the market clearing price and the marginal opportunity cost to other users would coincide. However, in the 2018 auction, Three was the last bidder to decrease demand and so effectively determined the market clearing price. The marginal opportunity cost to other users, on the other hand, is expressed by Telefonica's highest losing bid (Telefonica reduced demand from 55MHz to 40MHz at the price of £31.1m per 5MHz).

Given this, Ofcom considered the pros and cons of setting the ALF based on the market clearing price or on the marginal opportunity cost to other users. It concluded that, on balance, setting the ALF based on the marginal opportunity cost to other users is more appropriate.

This is because setting ALF based on the marginal opportunity cost to other users is more consistent with precedents: "*the marginal opportunity cost to other users … is the measure we generally focus on when considering fees for mobile spectrum*".[2]

[1] https://www.ofcom.org.uk/__data/assets/pdf_file/0024/42909/srsp-statement.pdf

[2] Ofcom's consultation, para 3.40

Ofcom further considered whether setting the ALF based on the marginal opportunity cost to other users could lead to an 'unfair outcome' or result in a distortion of competition and concluded that the risks were low.

On balance, Ofcom considers that "*the arguments in favour of using the marginal opportunity cost to other users … outweigh those in favour of using the higher market clearing price in this case*".[3]

Our assessment

Generally, we agree with Ofcom that setting the ALF based on the marginal opportunity cost to other users is preferable to setting the ALF based on the market clearing price. Indeed, in this case, the market clearing price effectively corresponds to Three's private valuation of incremental spectrum. Ofcom clearly stated in the past that its objective is not to establish the operator's own valuation, but "*the value that is denied to other operators by <the spectrum holder> continuing to hold this spectrum".* Therefore, Ofcom is right to focus on the opportunity cost to other users, rather than Three's private value of that spectrum.

However, we do not agree with Ofcom that both approaches are "*capable of securing the optimal use of spectrum*". Indeed, in some situations, setting the ALF based on the market clearing price could lead to inefficiencies. For example, this could occur if Three's valuation of some of its 3.4-3.6GHz spectrum falls below the market clearing price (£37.8m per 5MHz), but remains above £31.1m per block. In this scenario, the ALF set based on £37.8m per block would force Three to relinquish some of its spectrum. This would be inefficient as Three continues to be the highest-value user. This inefficiency would not arise if the ALF is set based on the marginal opportunity cost to other users.

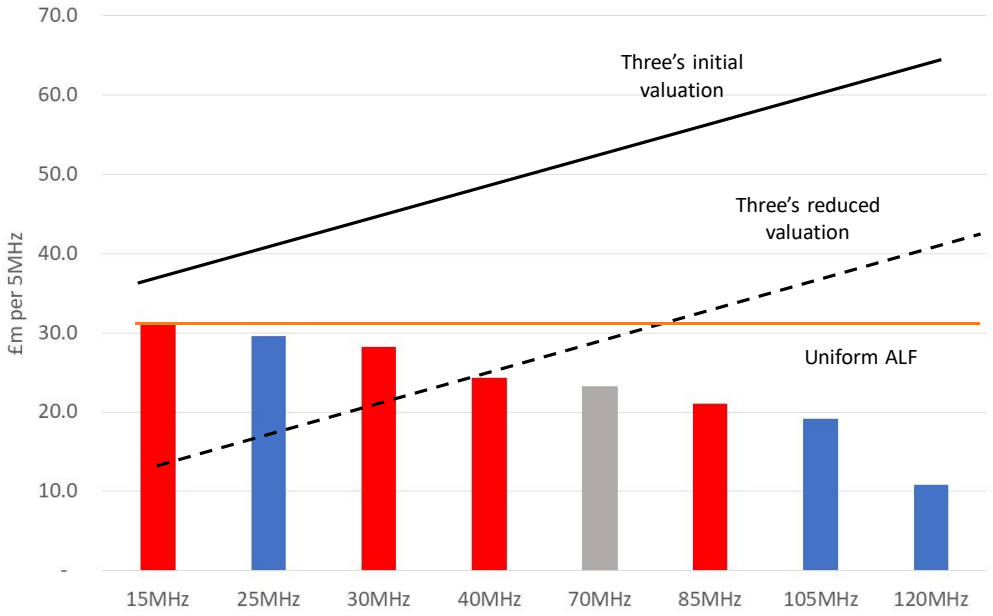
Hence, setting the ALF using the marginal opportunity cost to other users is more likely to produce an efficient outcome.

Ofcom's approach can lead to inefficient allocation of spectrum unless a non-linear ALF is used

We further note that although the marginal opportunity cost approach to setting ALF is expected to lead to a more efficient outcome than using the market clearing price, there are plausible cases where it will lead to inefficiencies. For example, if Three's valuation falls, and the ALF is set uniformly at £31.1m per block, Three would relinquish more spectrum than would be efficient. In Figure 1 below, we show the incremental excluded bids made by Telefonica, EE and Vodafone in the 2018 auction. These bids effectively reflect the opportunity cost of additional spectrum to these users. If the fall in the valuation of Three is as set out by the dotted line on the diagram, given the opportunity cost to the other bidders, Three would relinquish 75MHz (as Three's valuation falls below £31.1m per block) instead of 40MHz (where Three's valuation falls below other users' valuation). This would be an inefficient outcome.

[3] Ofcom's consultation, para 3.43

Figure 1 Uniform ALF leads to inefficiency



Source: Frontier Economics

In order to avoid this inefficiency, Ofcom should utilise the information available from the 2018 auction about other bidders' valuation of spectrum to design a step-function that would reflect the *diminishing* valuations of incremental spectrum expressed by these bidders. This would allow Ofcom to avoid inefficiencies in all cases.

Practical implementation of a non-linear ALF

In order to avoid/minimise the risk of inefficiencies in spectrum allocation, Ofcom can set the ALF to reflect the opportunity cost function as expressed in the 2018 auction (after effectively removing the bids of Three)[4]. We set out in the main body of our report a proposed diminishing ALF schedule that would meet this objective. This would imply that the ALF paid would be falling with the amount of spectrum held by Three, from £28.9m/5 MHz (for the first 10 MHz), to £9.0m/5MHz (for the last block).

The ALF step-function should be further adjusted downwards to reflect the fact that the 2018 values may potentially overstate the long-term value of the 3.4 and 3.6GHz bands

Although the 3.4GHz and 3.6GHz spectrum bands are likely to have similar long-term values, the prices paid (and the bids made) in the 2018 auction might overstate this long-term value. This is because the valuations of the operators in the 2018 auction may well have included a premium in order to be able to launch 5G services as soon as possible. As set out in Section 6, our modelling indicates

[4] The logic behind this is explained in a report prepared by Power Auctions for Three.

that this premium could be up to 10-15%[5]. In light of that, Ofcom should exercise caution and adjust the ALF downwards to reflect this.

[5] That is the operators potentially paid up to 10-15% more for 3.4GHz spectrum than they are likely to pay for 3.6GHz spectrum.

1 INTRODUCTION

In 2017, Three acquired UK Broadband (UKB) – a fixed wireless business – together with its spectrum holdings (40MHz in the 3.4GHz band and 80MHz in the 3.6GHz band). The initial terms of the spectrum licence expired in July 2018. UKB does not currently pay annual licence fees (ALFs) on the 3.4GHz spectrum, while the ALF for the 3.6GHz spectrum is set based on the Wireless Telegraphy Regulations 2011.

In April 2018, Ofcom completed the award of another 150MHz of the 3.4GHz spectrum, with all four mobile operators (EE, O2, Vodafone and Three) winning some spectrum. Ofcom is planning to award 120 MHz of 3.6GHz spectrum in 2020.

Ofcom is currently consulting on the level of ALF that should apply to UKB's 3.4GHz and 3.6GHz spectrum. In particular, it is considering how to take into account the outcome of the 3.4GHz spectrum award in setting ALFs for UKB's 3.4GHz and 3.6GHz spectrum.

Three has commissioned Frontier Economics to review Ofcom's proposal and to assess whether it is likely to achieve an efficient outcome, i.e. to ensure that the spectrum is put to the most productive use and consumer benefits are maximised.

Our report is structured as follows:

- Section 2 – we set out a framework for assessing the impact of Ofcom's proposed ALF for 3.4GHz and 3.6GHz spectrum, in light of Ofcom's duties and objectives.
- Section 3 – we summarise Ofcom's arguments for setting ALF based on the market clearing price vs. the marginal opportunity cost for other users.
- Section 4 – we demonstrate that setting ALF based on the marginal opportunity cost to other users is superior to setting ALF based on market clearing price, as it is more likely to achieve an efficient spectrum allocation.
- Section 5 – we demonstrate that Ofcom's approach could be optimised by using a non-linear ALF, taking into account the diminishing marginal valuations across 120MHz of spectrum.
- Section 6 – we discuss reasons why the price of 3.6GHz spectrum in 2020 could be lower than the price of 3.4GHz spectrum paid in 2018. In light of this, we propose that Ofcom exercises caution and adjusts the ALF function downwards.

2 A FRAMEWORK FOR ASSESSING THE IMPACT OF OFCOM'S PROPOSED ALF

In this section, we briefly discuss Ofcom's objectives with regards to spectrum management and, following from these objectives, we formulate the criteria for assessing the appropriate level of ALF. These are uncontentious, but it is helpful to set these out to assist with the subsequent evaluation of Ofcom's approach.

2.1 Ofcom's objectives with regards to setting spectrum fees

Ofcom's objectives with regards to spectrum management are set out in the 2006 Wireless Telegraphy Act. According to this, Ofcom is obliged to ensure that spectrum is used optimally, i.e. "*in a way that maximises the value that citizens and consumers derive from it, including broader social benefits*".[6]

Ofcom's duties also include:

- The promotion of competition in the provision of electronic communication services, ensuring that there is no distortion or restriction of competition;[7]
- Promoting efficient investment and innovation in new and enhanced infrastructure;[8]
- Ensuring that spectrum allocation is based on objective, transparent and proportionate criteria.[9]

Article 13 of the EU Authorisation Directive states that Member States may impose fees for the right of use of spectrum, which reflect the need to ensure the optimal use of this scarce resource. It is further stated that "*such fees should not hinder the development of innovative services and competition in the market*".

Ofcom sets out its rationale for using ALF for spectrum in the "Strategic Review of Spectrum Pricing (SRSP): The revised Framework for Spectrum Pricing."[10] Ofcom states:

"*benefits to society will be maximised over time if spectrum is priced to reflect opportunity cost. The opportunity cost is the price that would emerge in a well functioning market and reflects the value of spectrum to the best alternative use or user that is denied access to it.*" [emphasis added]

That is, Ofcom wants to incentivise spectrum users who do not have the highest value to relinquish this spectrum/ to sell it the higher-value users:

"*If the value of spectrum to a particular user is less than the opportunity cost, then the spectrum is, by definition, valued more by someone else. If spectrum were reassigned to that alternative use or user then we would expect that user to*

6 SRSP: The revised Framework for Spectrum Pricing, Consultation 29 March 2010 paragraph 1.7

7 Art 8 of the Framework Directive

8 Ibid

9 Art 9

10 https://www.ofcom.org.uk/__data/assets/pdf_file/0024/42909/srsp-statement.pdf

generate greater benefits to consumers and therefore increase the efficiency of the spectrum use".

In summary, therefore, Ofcom aims to set ALFs at a level that would result in an efficient allocation, i.e. at a level that would incentivise the existing users to relinquish their spectrum if there are other users who value that spectrum more highly.

Ofcom maintains that secondary spectrum trading is unlikely to be sufficiently effective to promote the optimal use of spectrum and, therefore, ALF is needed to ensure that the spectrum is allocated efficiently.

Ofcom also states *"It is important to ensure that each mobile operator has appropriate incentives to retain spectrum if it is the highest-value user of the underlying spectrum*."[11]

2.2 Translating Ofcom's objectives into a set of criteria for assessing the ALF

We note that the concept of 'optimal use' is largely synonymous with the economic concept of efficiency. The value to society is maximised if the scarce resource is used efficiently. There are different types of efficiency:

- *Static efficiency* (i.e. efficiency at a given point in time) assesses whether the allocation of inputs is optimal, i.e. welfare cannot be increased by using a different mix of inputs (*allocative efficiency*) and whether the output is produced at the lowest costs (*productive efficiency*).

  Static efficiency requires that all spectrum with value be used. If valuable spectrum is not used, then this will either result in some unmet demand, with a consequent loss of *allocative efficiency*, and/or the cost of production being unnecessarily raised, resulting in a loss of *productive efficiency*.

- *Dynamic efficiency* requires that incentives to invest and innovate are maximised, so leading to lower costs/ higher output in the future. Promoting dynamic efficiency is consistent with Ofcom's objective of promoting investment and innovation.

Therefore, in order to assess whether Ofcom's proposed fees contribute to fulfilling its duties, we need to assess whether the proposed ALF:

- ensures that the spectrum is used efficiently (static efficiency);
- promotes investment and innovation (dynamic efficiency);
- promotes competition; and
- maximises benefits to consumers.

These criteria are consistent with those used by Ofcom in Section 4 of the consultation document. However, we express some of these criteria in 'economic efficiency' terms. This allows us to observe interdependencies between the criteria

[11] Ofcom's consultation, para 3.6

(e.g. efficient allocations are expected to deliver maximum benefits to consumers) and allows us to carry out a more rigorous assessment of the available options.

3 OFCOM'S PROPOSED APPROACH TO SETTING 3.4-3.6GHZ ALF: A BRIEF SUMMARY

In this section, we summarise Ofcom's rationale for using ALF in this case and its assessment of the two potential approaches:

- To set the ALF using the market clearing price from the recent 3.4GHz auction; or
- To set the ALF using the marginal opportunity cost of spectrum to other users.

3.1 Rationale for using ALF

Ofcom refers to the SRSP and states that spectrum fees are needed "*to provide long term signals reflecting the value of the spectrum (based on its opportunity cost) in order to promote the optimal use of spectrum*".

Ofcom therefore proposes to introduce an ALF for 3.4GHz spectrum and to adjust the fees for the 3.6GHz spectrum as there is evidence of "*material misalignment between the current rates and the opportunity cost of the spectrum*" for which the ALF is set. More specifically, Ofcom is of the view that:

- Both 3.4GHz and 3.6GHz spectrum bands will have the same long-term value (as both bands have similar characteristics and will be used for 5G)[12];
- The bids and prices paid in the 3.4GHz auction provide evidence regarding the long term value of both 3.4GHz band and 3.6GHz bands;
- This value appears to be significantly higher than the current level of the ALF applied to UKB's 3.6GHz spectrum.

The purpose of its consultation is thus to assess the appropriate lump sum value of the 3.4GHz and 3.6GHz spectrum to use as an input to the ALF. Ofcom then proposes to annualise this lump sum value, i.e. to convert it into equivalent annual payments. This means the key issue in the consultation is to establish the appropriate value of 3.4GHz and 3.6GHz spectrum.

3.2 The value of 3.4GHz spectrum: 'market clearing price' vs. 'marginal opportunity cost to other users'

Ofcom notes that the term "spectrum value" can be interpreted in two ways.

- One approach is to use the market clearing price from the 3.4GHz auction. However, this price also reflects the private value of marginal spectrum to Three (as Three was the last bidder to reduce demand).

[12] Although there are currently some short-term constraints on 3.6GHz spectrum use (fixed links and satellite earth stations), these are expected to be removed by 2020.

- Another approach is to consider the marginal opportunity cost to other users, which is "*the next highest value of that spectrum to an organisation other than H3G*". This information can be inferred from the 3.4GHz auction bids.

MARKET CLEARING PRICE VS. MARGINAL OPPORTUNITY COST TO OTHERS

Ofcom notes that typically these two approaches would produce the same result. However, in this case they are different, as the ALF in this case will be paid only by Three (absent Three relinquishing any 3.4/3.6 GHz spectrum):

- Ofcom observes that in the 3.4GHz spectrum auction, the market clearing price was somewhere between £37.824m for 5MHz (at which price point there was some excess demand) and £39.715m for 5Mhz (at which price point there was no excess demand). Ofcom takes a conservative approach and assumes that the market clearing price corresponds to the lower bound, i.e. £37.824m. Ofcom considers that this price can be interpreted as the marginal opportunity cost of the spectrum in the auction as "*Three was prepared to pay this price for more spectrum than it ultimately obtained*". Therefore, £37.824m provides an estimate for "*the marginal opportunity cost for H3G of its holdings of 3.4GHz spectrum*".
- Using bid information from the 3.4GHz auction, Ofcom establishes that the marginal opportunity cost to other users is somewhere between £31.1m and £32.7m per 5MHz block (as Telefonica dropped demand from 55MHz to 40MHz at the price of £32.7m). Again, taking a conservative view, Ofcom takes the lower bound as the estimate of the marginal opportunity cost of the spectrum to other users, i.e. £31.1m.

Ofcom states that "*in principle, both the market clearing price (£37.8m) and the marginal opportunity cost to other users (£31.1m) could provide a measure of the market value of H3G's UKB 3.4GHz spectrum*".

When comparing the two approaches, Ofcom assesses which approach is more likely to incentivise the optimal use of spectrum (i.e. efficiency) as well as the impact on the other criteria, such as promoting competition, maximising benefits to consumers, and incentivising investment and innovation.

Our summary of Ofcom's assessment is presented in Figure 2.

In general, Ofcom considers that both approaches are "*capable of securing the optimal use of spectrum*". However, the market clearing price results in a higher ALF than ALF based on the marginal opportunity cost to other users.

Figure 2 Ofcom's assessment

	Market clearing price	Marginal opportunity cost to others
Which approach would secure the optimal use of spectrum?		
Arguments for:	Provides a long-term signal of the value of spectrum	The price signal ensures that the efficient user has the spectrum
Arguments against:	Risk of inadvertently setting ALF too high. Ofcom considers that this risk is mitigated by the fact that Three was willing to pay £37.8m in the auction	This approach could imply different ALFs charged to different users, which would imply changing ALF in case of a spectrum trade. Ofcom's view is that there might be no clear reason to change ALF following a trade.
Other considerations		
Arguments for:		Ofcom's view is that this approach is consistent with the approach used by Ofcom in the past. Using a different approach would be a departure from Ofcom's established position.[13]
Arguments against:	Risk of Three raising prices to customers. Ofcom considers that this risk is low given that Three will be paying the same price as other operators	Risk of an unfair outcome (different operators paying different amounts for similar spectrum) Risk of distorting competition (low given the values are reasonably close) Increased admin burden – insignificant as Ofcom does not envisage changing ALF frequently.

Source: Frontier summary, based on Ofcom's consultation document

Ofcom recognises that if the ALF is inadvertently set too high, it could threaten the optimal use of spectrum. The operators might "*over-economise on spectrum"* or might "*seek to recover any high costs from consumers through higher prices*". However, Ofcom considers that this risk is small in this case as "*all the MNOs, including H3G, were willing to purchase spectrum at the market clearing price in the 3.4GHz spectrum*".

Ofcom further notes that if it uses "the marginal opportunity cost to other users", it may result in different ALFs for the same spectrum for different users, which "*could conceivably have adverse consequences for future trading in that spectrum*". For example, if there were a trade between Three and Telefonica, this approach, applied strictly, would imply a need to use other operators' bids to set an ALF for Telefonica rather than to use Telefonica's own bid. Ofcom does not consider this to be a significant problem however, as the ALF does not need to be changed as a result of trade.

In addition to efficiency considerations, Ofcom also considers that the approach based on the marginal opportunity cost to other users is consistent with precedents. For example, Ofcom considers that "*the marginal opportunity cost to*

[13] Ofcom's consultation, para 3.40

other users … is the measure we generally focus on when considering fees for mobile spectrum".[14]

Ofcom also considers whether charging Three a lower ALF than the market clearing price could possibly result in "an unfair outcome", distort competition, and/or increase administrative burden to Ofcom.

- Ofcom recognises that if it charges Three an ALF based on the marginal opportunity cost to other users, it would introduce different prices to MNOs for the same spectrum. This could be considered unfair. However, the difference in prices charged would be fairly limited. In light of that, Ofcom believes that it is unlikely to introduce a competitive distortion.
- Ofcom does not consider administrative burden to be an issue as it does not envisage frequent changes to the ALF.

On balance, Ofcom considers that "*the arguments in favour of using the marginal opportunity cost to other users … outweigh those in favour of using the higher market clearing price in this case*".[15]

[14] Ofcom's consultation, para 3.40

[15] Ofcom's consultation, para 3.43

4 OUR ASSESSMENT OF OFCOM'S POSITION

This section is structured as follows:

- In Section 4.1, we revisit the issue of setting ALF under uncertainty, showing that the risks of inadvertently setting ALF too high or too low are asymmetric. If the ALF is set too high, it is likely to lead to significant efficiency losses due to spectrum being left unutilised.
- In Section 4.2, we assess the two approaches – using the market clearing price or the marginal opportunity cost – against a set of criteria. We agree with Ofcom that in this case setting the ALF based on the marginal opportunity cost to other users is preferable to setting the ALF based on the market clearing price.
- In Section 4.3, we set out our position with regards to spectrum trading. In our view, spectrum trading is likely to lead to an efficient spectrum allocation, even in the absence of ALF, and more trades are likely to take place as more spectrum is made available to the mobile industry.

4.1 The role of ALF in ensuring efficiency

In this subsection, we consider the role of ALF in attaining static and dynamic efficiency, and consider the risks of setting ALF under uncertainty.

Annual licence fees can, in principle, lead to an efficient allocation of spectrum by making it uneconomic for sub-optimal users to continue to use the spectrum.

When valuing spectrum, operators will take account of the ALFs associated with the spectrum, which will reduce the net value they place on the spectrum. If the forward-looking cost of the ALFs exceeds the value derived from using the spectrum, then the operator would seek to dispose of the spectrum, either through a trade or, if it is already in the hands of the optimal user, by returning the spectrum to the government.

In order to ensure that sub-optimal users vacate the spectrum, the licence fee should be set at a level that exceeds the value of the spectrum to sub-optimal users, but is below the marginal value for the optimal users. Setting the ALF in that range would ensure ***static (allocative) efficiency***.

Ensuring that ALF provides the right incentives critically depends on having reliable information on the values operators place on spectrum. However, these are rarely observable and may also fluctuate over time. Therefore, there is typically some uncertainty around the 'market value' of spectrum, which can have implications for setting ALF:

- **Scenario 1**: If the ALF is inadvertently set too high (above the market value of spectrum), then the spectrum will be returned by the current holder, but will not be taken up by any other operator at that price. The resulting welfare loss will be significant as all of the value associated with the unused spectrum will have been foregone.

- **Scenario 2**: If the ALF is set 'too low', then, absent trading, a sub-optimal user may continue holding the spectrum. As a result, there will be a potential welfare loss due to the difference in the value of the blocks between the optimal and sub-optimal users, but it is likely to be significantly smaller than the welfare loss in Scenario 1 (where the spectrum is returned and unused).

  If the existing allocation of spectrum is already optimal, there will be no welfare loss associated with setting ALFs below the opportunity cost to other users. Moreover, if spectrum trading is allowed, setting ALF too low would not preclude achieving the optimal outcome through trade.

More details on our assessment of the two scenarios above are provided in Annex A.

Below, we assess Ofcom's specific proposal, i.e. whether ALF should be set based on the market clearing price or the marginal opportunity cost to other users.

4.2 "Marginal opportunity cost to other users" is preferable to the market clearing price

Ofcom has used both 'marginal opportunity cost to other users' and 'average opportunity cost' in the past

Generally, we agree with Ofcom that setting the ALF based on the opportunity cost to other users is preferable to setting the ALF based on the market clearing price. This is consistent with Ofcom's objectives and its general approach to spectrum pricing as set out in the SPSR.

For example, in the SPSR, Ofcom states:

> "*The purpose of AIP*[16] *is to provide users with a sustained long-term signal of the value of the spectrum as indicated by its opportunity cost in the next highest use and, as a result, to give them incentives to use it in a way that maximises benefits for society over time*"[17] [emphasis added]
>
> "*Benefits to society will be maximised over time if spectrum is priced to reflect opportunity cost. The opportunity cost is the price that would emerge in a well functioning market and reflects the value of spectrum to the best alternative use or user that is denied access to it*."[18] [emphasis added]

Three effectively set the market clearing price in the 2018 auction when it reduced demand at the price of £39.715m (per 5MHz block). Therefore, the market clearing price reflects the private value of marginal spectrum to Three rather than marginal opportunity cost to other users.

Ofcom clearly states that its objective is not to establish the private value of spectrum to the spectrum holder, but to establish the value of spectrum to other users. For example, in the 900MHz and 1800MHz ALF Statement (2015), Ofcom says:

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16 AIP stands for Administrative Incentive Price, which is the same as ALF

17 SPSR, para 3.33

18 SPSR, para 3.41

> "*Taking Vodafone's holdings of 900 MHz as an example, we are not seeking to establish Vodafone's value of its 900 MHz licence. Instead it is the value that is denied to other operators by Vodafone continuing to hold this spectrum that is relevant to the opportunity cost. In particular, it is the value to the other operator that would gain the highest value if it were to acquire Vodafone's 900 MHz frequencies (or part of them)*". [emphasis added]

Overall, setting ALF based on the opportunity cost of spectrum to other users is consistent with Ofcom's general approach and the precedents of setting ALF for other spectrum bands.

Using the marginal opportunity cost to other users is more likely to maximise efficiency

Ofcom's assessment effectively assumes that both approaches would lead to an efficient outcome.

"… in principle, both the market clearing price and the marginal opportunity cost to other users are consistent with and therefore capable of securing the optimal use of spectrum".[19]

We do not think this is the case. Indeed, we have identified a scenario in which setting ALF based on the market clearing price may lead to inefficient outcomes. That is, these inefficient outcomes arise if Three's valuation of spectrum *falls* below the market clearing price, but Three remains the highest value user. This scenario is considered below.

SOURCES OF UNCERTAINTY IN SPECTRUM VALUATION/ REASONS WHY THREE'S VALUATION MAY FALL

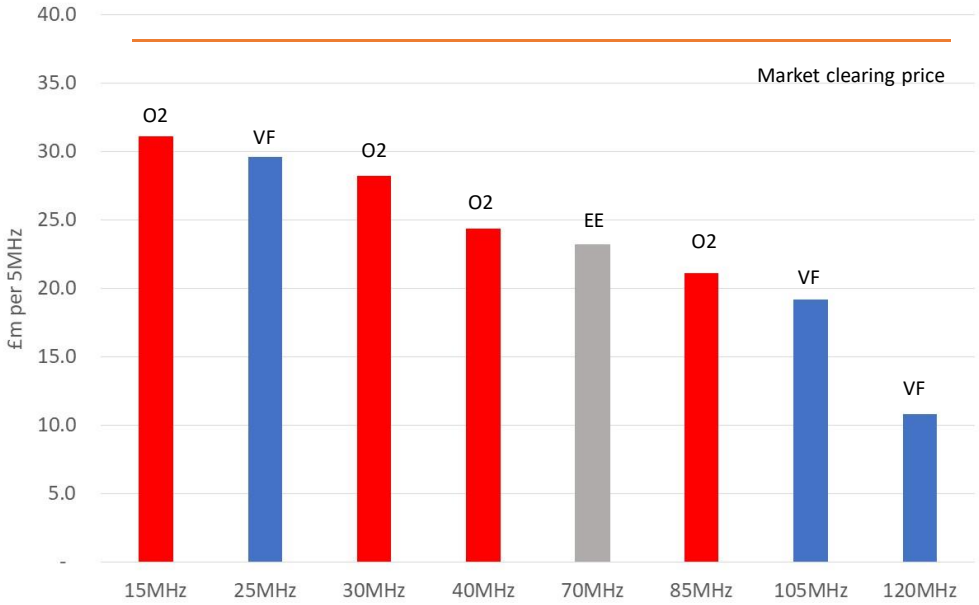
✂

Scenario 1: *Three's marginal valuation falls below £37.824m per 5MHz block, but remains above £31.1m per 5MHz block*. Assuming that other operators' valuations do not change, Three continues to be the highest value user. In this scenario, it is efficient for Three to continue using the spectrum. However, as its valuation falls below the market clearing price, it would want to sell/ relinquish some of its spectrum, which is inefficient. Moreover, Three might not be able to find a buyer as ALF at the market clearing price exceeds the other operators' valuations, which could lead to it returning this spectrum.

Indeed, bids placed in the 2018 auction suggest that the other operators reduced demand at lower prices than the market clearing price (Figure 3).

[19] Ofcom's consultation, para. 3.31

Figure 3 Incremental spectrum values, based on the bids made in the 3.4GHz spectrum auction (Principle stage)



Source: Frontier Economics based on the 3.4GHz auction results from the Principle Stage

More specifically:

- Telefonica expressed demand for additional 15MHz of spectrum at £31.1m per 5MHz;
- Vodafone - for additional 10MHz of spectrum at £29.6m, etc.

These incremental values are lower than the market clearing price. Therefore, it is unlikely that Three will be able to sell its unwanted spectrum if its valuation falls below £37.824m per 5MHz block.

In light of the other users' valuations, Three's only option would be to return its unwanted spectrum to Ofcom. This spectrum is likely to remain unused for a period of time, until Ofcom runs a competitive allocation in order to identify the highest value user. Given that in this scenario Three *is the highest-value user*, setting ALF at the market clearing price may lead to an inefficient outcome.

On the other hand, if the ALF is set based on the marginal opportunity cost to other users, Three's valuation will continue to exceed the ALF (as well as the marginal opportunity cost to other users). Three will continue using the spectrum, which is an efficient outcome in this case.

Therefore, setting the ALF at the marginal opportunity cost to other users is more likely to achieve Ofcom's objective of allocative and productive efficiency than the alternative approach (setting the ALF at the 'market clearing price').

Other considerations

Ofcom argues that setting different prices for different users of the same spectrum may be considered unfair and could potentially result in a competitive distortion.

However, we note that some auction formats can result in different prices paid by different bidders for the same spectrum. For example, in the 4G auction in the UK, which was a Combinatorial Clock Auction (CCA), prices were set based on the opportunity cost to other bidders. In the 900MHz and 1800MHz ALF consultation, Ofcom states:

"In March 2013 prices:

a) 4G Auction prices <of 2.6GHz spectrum> ranged from £3.8m per MHz to £5.7m per MHz

b) Our estimates of the opportunity cost in the 4G Auction ranged from £5.1m per MHz to £5.7m per MHz."[20]

These differences in prices were partly driven by the spectrum reservation for a 4th operator and partly by differences in the opportunity cost. When designing and implementing this CCA, Ofcom did not consider potential differences in prices to be problematic, as long as the auction produced an efficient allocation.

We would also not expect any differences in this instance to result in a competitive distortion, in the same way as slightly different prices paid in the 4G auction were not expected to lead to a competitive distortion in the 4G market.

Overall, efficiency arguments point towards the "marginal opportunity cost to other users" as a better approach to setting the ALF for 3.4-3.8GHz spectrum. Indeed, if the ALF is set above the marginal opportunity cost to other users and if Three's valuation falls below the market clearing price, there is a risk that Three will relinquish the spectrum even if it continues to be the highest-value user. In order to avoid this, Ofcom should set the ALF in line with other user's opportunity cost of additional spectrum.

This, however, would involve more than just looking at the marginal opportunity cost to Telefonica, but include a wider range of opportunity costs. This is discussed in detail in Section 5.

4.3 Spectrum trading should lead to an efficient allocation, even in the absence of ALF

We do not agree with Ofcom that ALFs are necessary to ensure efficiency. The fact that spectrum is tradable should result in an efficient allocation of spectrum across operators where barriers to trading are small. This is because there will be an incentive for an operator with a lower valuation to trade spectrum with an operator with a higher valuation, and receive a payment in return. As spectrum is successively traded, all spectrum should be assigned to those users that have the highest valuations. The trades between Qualcomm and Three, Qualcomm and Vodafone, and a purchase of UKB by Three provide the evidence that spectrum trades are happening. As more spectrum is made available to the mobile sector, we expect that more trades will take place.

Moreover, a relatively low number of trades may reflect the fact that current allocations are optimal rather than necessarily being an indication of failings in the

[20] https://www.ofcom.org.uk/__data/assets/pdf_file/0022/114736/consultation-alf.pdf

trading regime. Where spectrum trading can be implemented or improved, this should be considered the best option for ensuring allocatively efficient outcomes.

5 A DIMINISHING ALF FOR 3.4-3.6 GHZ SPECTRUM PROMOTES EFFICIENT ALLOCATION OF SPECTRUM

In Section 4.2 above, we have demonstrated that setting ALF based on the marginal opportunity cost is preferable to setting ALF based on the market clearing price.

However, to the extent that Ofcom sets the ALF for a large amount of spectrum (120MHz) and other users have expressed diminishing marginal valuations of additional spectrum in the 2018 auction, setting ALF uniformly at £31.1m per block could still lead to inefficiencies.

In this section, we show that in order to achieve efficient outcomes in all scenarios, Ofcom should set the ALF based on the declining opportunity costs to other users. This is more appropriate, given that the ALF is set for a large amount of spectrum and there is transparent and timely information available from the auction on the marginal valuation of different amounts of spectrum for different (potential) users.

5.1 ALF that reflects diminishing opportunity cost will minimise the risk of inefficient spectrum allocation

An example below demonstrates that if Three's valuation falls significantly, while the ALF is set uniformly at £31.1m per block (Telefonica's marginal opportunity cost), the outcome would be inefficient.

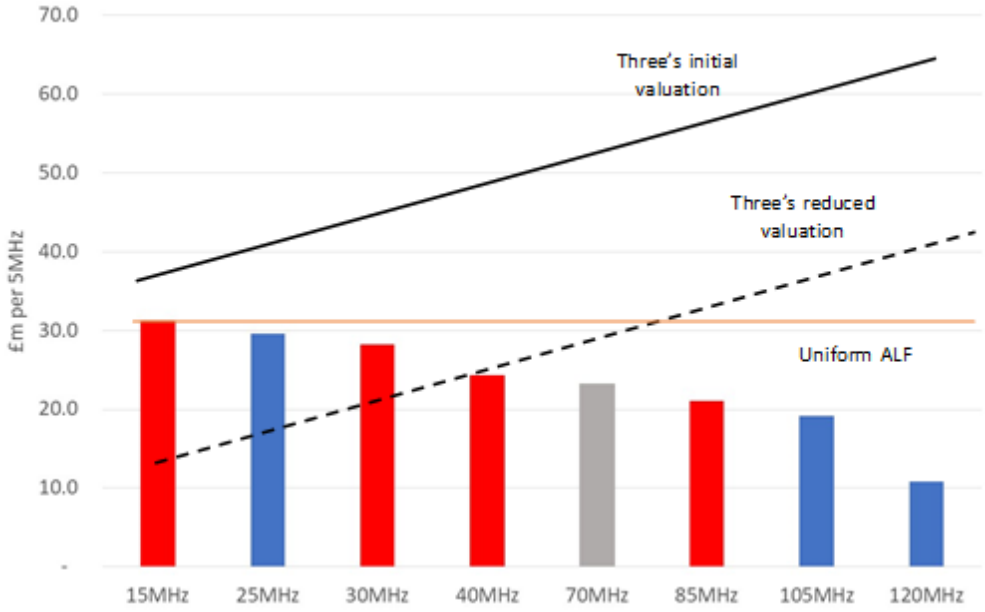
Scenario 2: *Three's valuation falls below £31.1m per block for c.75MHz* (as illustrated by the diagram below). Although Three's valuation falls in general, it falls below other users' valuation[21] only for 40MHz of spectrum. Therefore, Three continues to be the highest value user of 80MHz of spectrum.

Given that the ALF is set at a uniform level of £31.1m per block (annualised), Three will be incentivised to sell/ relinquish 75MHz of spectrum (i.e. the spectrum for which Three's valuation falls below £31.1m per block). This is clearly inefficient as Three continues to be the highest value user of 80MHz and should only relinquish 40MHz.

Moreover, out of 75MHz Three wants to sell, it will only be able to sell 15MHz to Telefonica. It will not be able to sell the remaining 60MHz as the ALF is set above the other users' opportunity cost of that spectrum. The spectrum will be returned to Ofcom and remain unused until Ofcom runs a competitive tender to re-allocate it.

[21] Other users' valuations are expressed by the excluded bids in the auction

Figure 4 Uniform ALF leads to inefficiency



Source: Frontier Economics

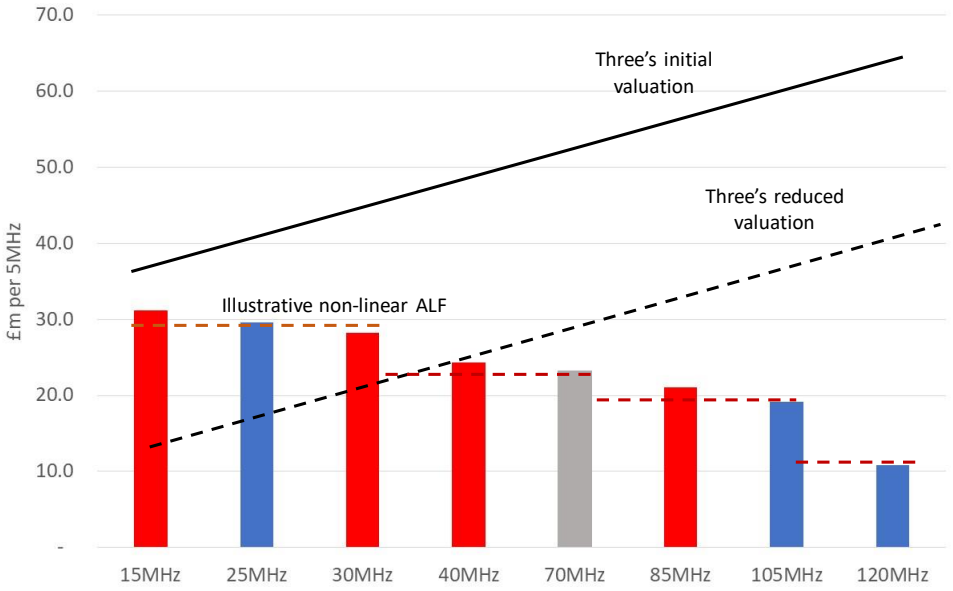
It is clear that a uniform ALF set at £31.1m per block leads to an inefficient outcome:

- Three is forced to relinquish more spectrum than is efficient - 75MHz (as Three's valuation falls below £31.1m per block) instead of 40MHz (where Three's valuation falls below other users' valuation); and
- It jeopardises efficient trades as the ALF is set too high.

Rather than setting the ALF at a constant level across 120MHz of spectrum, Ofcom should take into account the diminishing valuations of 3.4 GHz revealed in the 2018 auction. In principle, the ALF function could exactly match the excluded bids in the 2018 auction or, to the extent that some bids/ valuations are similar, the ALF function could be smoothed (as illustrated in Figure 5).[22]

[22] We discuss practical implementation in more detail below.

Figure 5 This inefficiency is addressed if ALF is set in line with declining opportunity costs



Source: Frontier Economics

To the extent that the ALF step-function is informed by the diminishing marginal valuations of other operators, the risk of inefficiencies is minimised. Indeed, in our scenario 2, Three would only want to relinquish 40MHz of spectrum, which is efficient. Moreover, Three will be able to find trading partners as the ALF is set based on the other users valuations. Therefore, a situation, where spectrum is returned to Ofcom and left unused because the ALF is too high, is avoided.

We note that in the past (in the context of setting 900MHz and 1800MHz ALF) Ofcom accepted that non-linear ALF may be conceptually the right approach.

"*The values for 800 MHz and 2.6 GHz of the marginal bidder, or non-holder (NH) of the licences for ALF spectrum, are non-linear. This suggests that, in theory, if the structure of demand of the highest-value NHs <non holders> for 900 MHz and 1800 MHz follows a similar pattern, the optimal ALF would also be non-linear*." [23]

However, Ofcom rejected it in favour of a uniform ALF because of practical difficulties and also because it would be "*a break with past practice"* as spectrum fees have always been set at a uniform £/MHz.[24]

We appreciate that in the context of setting 900MHz and 1800MHz spectrum ALF Ofcom did face a number of difficulties, such as:

- a lack of information on operators' valuations of 900MHz and 1800MHz (as 900MHz and 1800MHz spectrum bands were never auctioned in the UK); and
- CCA auction format/ bidding for packages of 800MHz and 2.6GHz (which Ofcom used as proxies for the 900MHz and 1800Mhz spectrum values), which

[23] https://www.ofcom.org.uk/__data/assets/pdf_file/0030/76926/annexes_1-7.pdf, A6.98

[24] Ibid, A6.97-A6.99

made it difficult to establish the opportunity costs even for the 800MHz and 2.6GHz frequencies.

However, in the context of setting the ALF for 3.4-3.8GHz spectrum, the same issues do not arise. Ofcom is setting the ALF for similar frequencies to those auctioned in 2018. Moreover, unlike in the case of 900MHz and 1800MHz ALF, bids made in the 2018 auction provide accurate, timely, and transparent information on the diminishing marginal valuations of additional spectrum for other users.

Therefore, in this case, arguments for not using information on declining marginal valuations/ not setting non-linear ALF appear to be weaker. Given there are plausible scenarios where a uniform ALF set at £31.1m per 5MHz block could lead to inefficient outcomes, Ofcom should not be concerned with breaking with "past practice", but should aim to achieve efficiency, in line with its statutory duties.

5.2 Three's winning bids should be excluded from the ALF calculations

A report by Power Auctions (commissioned by Three) argues that in order to calculate the opportunity cost of Three's ALF spectrum, Ofcom should exclude not just Three's losing bids, but also Three's winning bids.

"*the calculation of the marginal opportunity cost to other users should exclude the impact of H3G's winning bid for 20 MHz in the 3.4 GHz band. The correct calculation can be carried out using only losing bids. First, observe that Telefonica's demand drop at £31.1 million does not correspond to the correct marginal opportunity cost since Telefonica reduced its demand from 55 MHz to 40 MHz for a total drop of 15 MHz (less than 20 MHz won by H3G). As a result, the next-highest losing bid must be considered. The next rejected bid was placed by Vodafone who reduced its demand from 60 MHz to 50 MHz at £29.6m. Now the sum of rejected bids is 25 MHz (more than 20 MHz won by H3G) and the price of £29.6m determines the correct marginal opportunity cost to other users.*

To phrase it differently, Telefonica's £31.1 million bid determines the marginal opportunity cost of the spectrum acquired in the PSSR auction. However, it does not demarcate the marginal opportunity cost of H3G's prior holdings (the UKB spectrum), since without H3G's winning bid in the auction, Telefonica's £31.1 million bid could have been fulfilled without any of the UKB spectrum."[25]

In our proposed practical implementation below, we take this recommendation into account and remove Telefonica's £31.1m bid, as this bid represents the opportunity cost of the spectrum that Three won in the auction.

5.3 Practical implementation

In this sub-section, we look at practical implementation of a non-linear ALF. That is, we identify questions that might arise and respond to those questions.

[25] Power Auctions report

How granular should the step function be?

Or, to put it differently, how should the ALF steps be constructed? – In principle, Ofcom should closely follow the opportunity cost function expressed in the 2018 auction (after removing Telefonica's highest bid) and set ALF steps as follows[26]:

- £29.6m per block for the first 5MHz block (based on Vodafone's excluded bid),
- £28.2m for the next 5MHz (based on Telefonica's excluded bid),
- £24.4m for the next 10MHz (based on Telefonica's excluded bid);
- £23.2m for the next 30MHz (based on EE's excluded bid),
- £21.1m for the next 15MHz (based on Telefonica's excluded bid),
- £19.2m for the next 20MHz (based on Vodafone's excluded bid),
- £10.8m for the next 20MHz (based on Vodafone's excluded bid),
- £9.8m for the next 10MHz (based on EE's excluded bid),
- £9.0m for the final 5MHz (based on Vodafone's excluded bid),

However, recognising that some valuations are fairly close, Ofcom could 'smooth' the step function and to construct a non-linear function as follows:

- the first step at £28.9m[27] per block for the first 10MHz,
- the second step – at £23.5m[28] per block for the following 40MHz,
- the third step – at £20.0m[29] per block for the following 35MHz; and
- the fourth step - at £10.3m[30] per block for the final 35MHz.

ALF steps are not frequency-specific

We do not propose to link specific 'rungs' of the ALF step-function with specific frequencies owned by Three. That is, if Three wants to sell or return some of its spectrum, it should be able to choose whether to return 3.4GHz spectrum or 3.6GHz spectrum (and which specific blocks within a given band).

Applying a non-linear ALF in practice

When applying a non-linear ALF in a situation where Three wants to sell or return some of its 3.4-3.6GHz spectrum, it is important that the highest value ALF should be applied first.

To illustrate this point (and assuming that the ALF has 4 rungs as set out above):

- If Three wants to sell/ return 10MHz of 3.6GHz spectrum, it should be able to reduce its total ALF bill by £28.9m * 2 = £57.8m (annualised);

[26] We appreciate that in all cases these values are lump-sum values, which need to be annualised.

[27] The weighted average of the first two valuations

[28] The weighted average of the following two valuations

[29] The weighted average of the following two valuations

[30] The weighted average of the final three valuations

- If later it wants to sell an additional 10MHz of 3.4GHz spectrum, it would save £23.5m * 2 = £47.0m (annualised), etc.

The same calculations would apply if Three wanted to sell 3.4GHz first and 3.6GHz spectrum later (i.e. the ALF steps should not be linked to specific frequencies).

Step-function ALF and spectrum trading

As discussed above, a step-function ALF based on the opportunity costs to other users is more likely to lead to an efficient outcome than a uniform ALF and, therefore, should incentivise trading if Three's valuations fall.

The same rule should apply to trading as to relinquishing spectrum - the highest marginal ALF should apply first. If Three sells some of its spectrum to another user, its ALF bill is reduced, with the ALF obligation now applying to the purchaser of the spectrum. For example, if in the example above, Three sells 2 blocks of 3.6GHz spectrum to Telefonica, Three's ALF bill would be reduced by £28.9m * 2 = £57.8m (annualised), while Telefonica's ALF bill would increase by the same amount.

5.4 Conclusions

Overall, as demonstrated above, setting ALF based on the marginal opportunity cost to other users is more likely to lead to an efficient outcome than setting ALF based on the market clearing price. However, as the opportunity costs for additional 3.4 GHz spectrum are diminishing, setting the ALF uniformly can lead to an inefficient allocation of spectrum (illustrated by Scenario 2 above). Ofcom can minimise the risk of such an inefficiency by setting the ALF as a step-function using the diminishing valuations of opportunity cost from the 2018 auction. Such an approach is both justified on efficiency grounds and can be implemented in practice.

6 VALUING 3.4-3.6GHZ SPECTRUM OVER TIME

As noted above, Ofcom considers that the 3.6GHz spectrum is very similar to the 3.4GHz spectrum (auctioned in 2018) and, therefore, "*in the long-term … the 3.4GHz and 3.6 GHz spectrum will have the same value*". Ofcom further states: "*we therefore consider that the bids and prices indicated in the 3.4GHz award also provide a good indication of the value of UKB's 3.6GHz spectrum in the long term*".[31]

In the long term, the value of 3.4GHz and 3.6GHz spectrum is likely to be similar. However, by relying exclusively on the prices paid and bids made in the 2018 auction, Ofcom might overstate the long-term value of these spectrum bands. This is because, unlike in the previous cases where ALF was set for the spectrum that had been in use by mobile operators for a long time (900MHz and 1800MHz), the 3.4-3.8GHz bands are only now being standardised for mobile use. Therefore, there is a risk that operators' valuations may change over time and, therefore, the prices paid in the 2018 auction might not necessarily represent an accurate long-term value of the 3.4-3.8GHz bands.

Indeed, in its analysis, Ofcom overlooks the sequential nature of the two auctions (the 3.4GHz spectrum auction in 2018 and the future 3.6GHz auction in 2020). Economic theory predicts that prices in sequential auctions should be similar, if bidders are risk-neutral and all other conditions remain the same. However, in this case, conditions are likely to change between 2018 and 2020, with operators having been likely to have placed a premium on obtaining the spectrum earlier.

More specifically, in 2018, the 3.4GHz spectrum was the first 5G band made available to mobile operators in the UK. It was important for mobile operators to secure a certain minimum amount of this spectrum in order to be able to launch 5G services as soon as possible. After securing the spectrum, announcements about the launch of 5G services followed:

- Vodafone was the first operator in the UK to carry 5G traffic over its commercial network in Greater Manchester, and is now extending its 5G network to 6 more cities in 2019. In its press release, Vodafone acknowledges the importance of 3.4GHz spectrum for its 5G roll out plans, stating that "*Vodafone secured the largest block of this 5G spectrum at this year's auction*".[32]
- EE has announced that it will launch 5G in 16 cities in 2019[33], stating that "*5G, at launch, will be another significant step forward in the way consumers experience mobile broadband – lower latency [delay] than 4G and more capacity for users to share. And it will evolve over time to see more capacity, even lower latency, the ability to connect billions of devices, and the network slicing capability that opens up vertical markets and new applications.*"[34]

[31] Ofcom's consultation, para 2.17

[32] https://mediacentre.vodafone.co.uk/news/vodafone-first-full-5g-in-the-uk/

[33] https://newsroom.ee.co.uk/ee-announces-5g-launch-locations-for-2019/

[34] https://5g.co.uk/news/ee-5g-lite-dismissal/4388/

- Three announced that it is investing £2 billion in its network and is planning to launch 5G in 2019.[35]

The first 5G phones are expected to be available from LG, Samsung and a number of other manufacturers from February 2019, while a 5G iPhone is expected to be available in 2019/20.[36]

When advertising their 5G-enabled phones and tariffs, the operators are likely to target high-end customers and sell these 5G-enabled services at a premium. This is similar to the approach taken by EE when it first launched 4G services in the UK, 6-12 months ahead of its competitors.[37] In fact, by launching first, EE secured a strong position in 4G for years to come. Even in 2018, EE remained ahead of its competitors with a 35% share in 4G. For a comparison, EE's overall market share is 30%.[38]

Had an operator failed to acquire the 3.4GHz spectrum in 2018, it would have had to wait until the next auction in 2020. In the meantime, the other operators would be able to gain an advantage in the new 5G market. As EE's 4G experience suggests, this initial advantage (or disadvantage) may last for a number of years. In light of these considerations, it was important for mobile operators to acquire some 3.4GHz spectrum in 2018, which would have been reflected in their valuations and the bids made.

We have undertaken some basic modelling[39] to seek to obtain an indication of the likely premium that mobile operators could be expected to place on obtaining the spectrum in 2018, rather than 2020. This indicates that the operators could include a 10-15% premium in the value of the 3.4GHz spectrum acquired in 2018: this is because additional 3.6GHz spectrum acquired in 2020 will not have the same commercial value as the 3.4 GHz spectrum acquired in 2018, because it will not lead to the 'creation' of a new market.

Conclusion

As discussed in Section 4.1 above, setting ALF under uncertainty creates asymmetric risks. Efficiency losses (both static and dynamic) are likely to be greater if ALF is inadvertently set too high than if it is set too low. Therefore, Ofcom should exercise caution and adjust the ALF step function downwards to reflect the likely premium included in the 2018 spectrum bids (all else the same).

35 https://5g.co.uk/news/three-launch-2019/4586/

36 https://5g.co.uk/phones/

37 https://www.theguardian.com/technology/2012/oct/29/ee-launches-uk-4g-mobile-network, https://www.digitaltrends.com/mobile/details-on-uks-first-4g-network-to-be-named-ee-emerge/

38 Telegeography

39 Our modelling is discussed in more detail in Annex B

7 CONCLUSIONS

In order to minimise the risk of inefficient allocation of spectrum, Ofcom should use a non-linear ALF by using the diminishing opportunity cost function as revealed in the 2018 spectrum auction. Recognising that some of the expressed values are reasonably close, this function can be smoothed as follows:

- the first step should be set at £28.9m[40] per block for the first 10MHz,
- the second step – at £23.5m[41] per block for the following 40MHz,
- the third step – at £20.0m[42] per block for the following 35MHz; and
- the fourth step - at £10.3m[43] per block for the final 35MHz.

If Three wants to sell or relinquish some of its 3.4 or 3.6GHz spectrum, the highest ALF should apply first. This would ensure that Three has the right incentives to relinquish the spectrum if its valuation falls below that of the next highest user.

In Section 6 we further argue that, although the 3.4GHz and 3.6GHz spectrum bands are likely to have similar long-term values, the prices paid (and the bids made) in the 2018 auction might potentially overstate this long-term value. This is because in 2018 the operators were prepared to pay a premium for the 3.4GHz spectrum band in order to be able to launch 5G services as soon as possible. Our modelling shows that this premium could be up to 10-15%.[44] In light of that, Ofcom should exercise caution and adjust the ALF downwards to reflect this.

[40] The weighted average of the first two valuations

[41] The weighted average of the following two valuations

[42] The weighted average of the following two valuations

[43] The weighted average of the final three valuations

[44] That is the operators potentially paid up to 10-15% more for 3.4GHz spectrum than they are likely to pay for 3.6GHz spectrum.

ANNEX A SETTING ALF UNDER UNCERTAINTY: ASYMMETRIC RISKS

Setting ALF 'too high' is likely to lead to greater welfare losses than setting ALF 'too low'

Overall, it appears that the risks associated with setting the 'wrong' ALF (i.e. an ALF which diverges from the true market value) are symmetric. In the case of the ALF being set below the market value, there may be no welfare loss at all if the current allocation is optimal. Even where the current user is not the highest-value user, the value potentially foregone will only be the difference between the valuations placed on the marginal blocks of spectrum by the optimal user and the current user .

In the case of the ALF being set above the true market value, the spectrum may become unused, and the entire value associated with the spectrum will be foregone from the moment that the spectrum is returned. Even prior to the spectrum being returned, there is likely to be a period of sub-optimal use as the holder migrates traffic and reduces demand in order to minimise the disruption associated with the spectrum being returned. And in this circumstance, even if the ALF is reduced and the spectrum is subsequently re-allocated to the same operator, by auction or other mechanism, there will be a lag before it is used optimally as the operator will have to make investments to reconfigure its network.

Therefore, to the extent that the market value of spectrum is uncertain, it is important that Ofcom adopts a conservative approach and sets ALF at the lower bound rather than upper bound estimate of the market value.

ANNEX B 3.4GHZ PRICE PREMIUM: DETAILS OF OUR MODELLING

Frontier Economics has been commissioned by Three to estimate the high-level value of 3.4-3.6GHz spectrum, depending on when this spectrum is acquired (in 2018 vs. in 2020). This annex summarises our estimation approach and outlines the key assumptions we have made.

Overview of our modelling approach

We specifically focused on estimating the value to an operator of acquiring 3.4GHz spectrum in 2018 in order to launch 5G services in 2019 rather than in 2020-21. We modelled the value of spectrum in two scenarios, in both cases assuming that all other operators acquired the spectrum in 2018:[45]

- **Scenario 1:** The operator was able to acquire the spectrum in 2018
- **Scenario 2:** The operator would not acquire the spectrum until 2020

We compared the total value to the operator of spectrum under each scenario to estimate the portion of that value that depends on the timing of its acquisition.

Details of modelling approach

We started from the assumption that an operator would be unable to offer 5G services without 3.4GHz spectrum. The incremental value of this spectrum can then be measured by the additional variable margin that an operator could earn if it held the spectrum and launched 5G services. This additional margin results from (i) being able to serve a particular customer segment (those who want to have access to 5G services) and (ii) being able to earn a higher margin on 5G services than 4G services[46], as a result of:

- operators being able to price 5G higher than current 4G services; or
- operators no longer being able to price 4G services at the same level due to 5G becoming the 'new normal'; and/or
- 5G technologies offering operators greater profit margins via greater efficiency.

We assume that mobile consumers make a two-step decision: first assessing whether they will take up a 5G service, then choosing an operator:

- In Scenario 1, we assume that all operators attain the same market share for 5G customers as for non-5G customers.
- In Scenario 2, we assume that the operator which faces a delay in acquiring 3.4GHz spectrum achieves a 5G market share below its current overall share, following a path of five years to 'converge' its 5G share to its overall market share. This reflects the first-mover advantage of the operator(s) first offering 5G services.

[45] Our calculations therefore reflected the value to an operator of not being at a competitive disadvantage.

[46] In some scenarios, we assume that 5G margin will be the same as 4G margin (i.e. no 5G price premium).

The impact of this disadvantage is in a lower overall market share (since the operator initially has no 5G market share and thereafter a lower share than it would otherwise have if it were able to acquire 5G spectrum at the same time as the other operators). Moreover, it could also result in a lower contribution margin per customer (assuming there is a 5G price premium).

To quantify the total impact we calculate a 15-year NPV of the variable margins generated under each scenario.

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