Deriving market clearing prices for 800 MHz spectrum from the UK 800MHz/2600MHz auction

A REPORT PREPARED FOR VODAFONE

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Executive summary

Ofcom have attempted to derive 'full market value' from the recent UK auction as an input to setting the ALFs for 900 MHz and 1800 MHz spectrum.

An ALF regime can promote an efficient allocation of spectrum when the fees reflect market value. Market value will represent the market clearing price for spectrum, and market clearing prices for the purposes of setting ALFs, will represent the opportunity costs of allocating an increment of spectrum to the value user rather than to the next-highest value user. The market value captures the private benefits which could be gained if the relevant increment of spectrum ('incremental spectrum') were allocated to an entity other than the highest value user, and which are therefore forgone by allocating it to the winning bidder. Setting the ALF at this level will ensures that spectrum can only be held by the user that is able to generate the most value from it, thereby promoting efficient allocation.

However, the UK auction had a number of features which means that bids may not accurately reflect potential users' private values for incremental spectrum, being the value that such users can generate from incremental spectrum. In particular, Ofcom set relatively high reserve prices for 800 MHz spectrum, in contrast to their previous policy of setting "low but non-trivial" reserve prices. These reserve prices meant that most bidders did not submit bids showing their private valuation of incremental 800 MHz spectrum. In addition, the design of the auction, by treating H3G as an 'opted in' bidder, gave it an increased incentive to bid strategically. As a result of these and other factors, operators' bids will not provide a full picture of their private valuations of incremental spectrum, and may also not reflect 'truthful' indications of the operators' private values. The impact of these and other factors should be taken into account when analysing the bid data from the auction in order to estimate the market value of incremental 800 MHz spectrum.

Ofcom have proposed relying on a methodology for estimating the value of 800 MHz spectrum from the auction results known as the LRP method. The LRP method does not attempt to estimate market clearing prices for incremental spectrum, but instead attempts to decompose prices paid by winning bidders for large packages of spectrum. Ofcom has not explained how reliance on such a decomposition approach would approximate market clearing prices and hence lead to ALFs which could promote efficient spectrum allocation.

The reliance on the LRP methodology is flawed, as the methodology as applied does not take into account the limitations of the auction results and bid data. In particular, the LRP method *over-estimates* the market clearing price for incremental 800 MHz spectrum. This partly reflects the fact that the prices paid are in part determined by the high reserve price for blocks of 800 MHz spectrum: this clearly influence the results of the methodology. As the reserve prices do not

reflect true opportunity costs for spectrum they should not feed into any estimate of the market value of spectrum. Removing the reserve price "bids" from the auction price determination algorithm results in materially lower (calculated) spectrum value estimates. However such removal also results in a much poorer fit between the results of the LRP methodology and operators' bids, showing that the implicit assumption that the prices paid reflect a common (linear) market value does not hold. This indicates that the LRP method does not provide robust estimates of the market value of incremental spectrum.

The fact that the reserve price of £225 million for a 5 MHz block of 800 MHz spectrum formed part of the calculation of the prices paid in the auction indicates that the true opportunity cost of an incremental block of spectrum is less than this: i.e. in the absence of one of the bidders, there was no operator willing to pay more than the reserve price for one of the available blocks of spectrum. This shows that £225 million represents an upper bound for the market value of 5 MHz of 800 MHz spectrum.

The UK auction did provide some direct evidence of the opportunity cost of 800 MHz spectrum: EE's bids revealed information on their marginal valuation of 5 MHz blocks of 800 spectrum. Furthermore, the available evidence is also consistent with EE being considered to be the highest value excluded user for low frequency spectrum, including the 900 MHz spectrum subject to ALF:

- EE could be expected to have a relatively high private valuation of low frequency spectrum, given their relatively small holdings of low frequency spectrum compared to their subscriber base;
- given their large low frequency holdings[1], Vodafone and O2 are likely to have relatively lower incremental private value for additional low frequency spectrum; and
- H3G's bids in the auction indicate that they also have a relatively low valuation for additional low frequency spectrum.

EE's expressed valuation of a single 5MHz block of 800 MHz spectrum was generally £230 million[2]. Operators' valuations of a first block of low frequency spectrum will tend to be higher than incremental spectrum after this, all other things being equal, as there is a 'coverage premium' attached to the first block. As EE acquired a single low frequency block in the auction, £230 million can be considered therefore an upper bound on EE's valuation of additional blocks of

1 Vodafone and O2 showed very high private valuations for the low frequency spectrum they acquired in the auction as this spectrum was required for them to offer competitive LTE services. They are also likely to have high private values due to

2 EE made three pairs of bids which showed higher differentials for a single block of 800 MHz spectrum. However these appear to reflect strategic value.

low frequency spectrum, and hence the market value of 800 MHz spectrum for current purposes. It is possible to adjust EE's bid data to estimate its marginal valuation for an additional non-contiguous 5 MHz block.. Making this adjustment results in an estimated private valuation for EE for incremental 2 x 5 MHz block of 800 MHz spectrum of between £179 million and £215 million. This range provides the best estimates of the market value of incremental 800 MHz spectrum that can be derived from the UK auction.

1 Market clearing prices for spectrum

Ofcom has been directed to set ALFs with reference to the 'full market value' of the spectrum in question. Ofcom defined full market value as follows:

"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."[3]

The market value reflects the opportunity cost of the spectrum not being exploited by the excluded users (i.e. the 'cost' to society of allocating the spectrum to the current user instead of another user). This is revealed by the highest prices that would be paid by (i.e. the private valuation of) one of the excluded users.

In this chapter we outline the framework in which it is appropriate to consider market prices in order to understand the degree to which the recent UK auction can provide information about such prices for the purposes of setting ALFs. First we set out how spectrum can generate value for users and then we set out how the combination of values for all actual and potential users can be used to define the relevant market price of spectrum.

1.1 The value of spectrum

Spectrum suitable for mobile communications is a scarce resource. That is, demand for spectrum at zero price[4] is expected to exceed supply. For any given block of spectrum, there would generally be an expectation that more than one operator/user would have a positive value from using that spectrum. As a result, there is an opportunity cost from allocating a block of spectrum to one operator or user rather than another, reflecting the potential value of the spectrum to the operator who is not allocated the spectrum. The market value of the spectrum is therefore a function of the value that actual and potential users attach to the use of the relevant spectrum.

When considering the value of a block of spectrum for any individual mobile operator, it is likely to reflect a possible combination of a range of factors which may include:

- The ability to offer products and applications that they would not be able to offer without the block of spectrum ("capability");

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3 Consultation on assessment of future mobile competition and proposals for the award of 800 MHz and 2.6 GHz spectrum and related issues, published by Ofcom on 22 March 2011, paragraph 10.3

4 In the absence of any further constraints on spectrum holdings and usage.

- The ability to offer services in areas where it would be uneconomic to offer services otherwise ("coverage");
- The ability to continue to offer services using existing networks and existing mobile devices ("sunk costs");
- The ability to deliver incremental traffic using less equipment ("capacity"); and
- The ability to exclude other operators from using the spectrum and to reduce competition and hence potentially increase market share and/or prices ("strategic").

The importance of these factors will differ between different blocks of spectrum for a given operator and between different operators for a given block of spectrum. The absolute and relative significance of these factors will also in general be expected to be a function of the market conditions in different countries, the different types and quantities of spectrum on offer, the auction award design/rules, and the current and expected market structure of mobile markets.

1.1.1 Combinatorial factors

The value of any particular incremental block of spectrum will depend on the existing spectrum holdings of the operator in question. For example if an operator already has spectrum which provides the capability to offer a technology such as LTE, the incremental value of spectrum which provides LTE capability is likely to be significantly lower than for a similar operator who does not yet hold spectrum which provides LTE capability.

As such there may not be a single market value of a block of spectrum, but this will depend on both the existing spectrum holdings of operators and any complementary spectrum that may be available at the same time.

In general the private value of spectrum to an operator will decline with the volume of spectrum[5].

1.1.2 Willingness to pay versus opportunity cost

The market price that would achieve the efficient use of spectrum, should reflect the opportunity cost for the use of the spectrum – put differently, it should reflect the value of the block of spectrum in the most productive alternative use. Given the wide variation in the characteristics of the relatively small number of potential operators of mobile spectrum, there may be significant differences in

5 This decline may not be monotonic: for example certain amounts of contiguous spectrum may offer increased capability compared to lesser amounts).

their willingness to pay for any given increment of spectrum. As such it is possible than the willingness to pay (private value) of the highest value user of a block of spectrum is considerably higher than this opportunity cost[6]. Deriving therefore market prices from valuations of spectrum that may be reflecting the 'private' value of successful bidders could lead to a significant over-estimation of the 'true' market price, which reflects the opportunity cost of unsuccessful bidders.

1.1.3 Market values for determining ALF

In certain circumstances, setting ALF for spectrum at a market clearing price could result in improvements in efficiency, as spectrum would be relinquished by an operator whose valuation is less than that price allowing the operator who has a greater valuation to acquire the spectrum.

As any relinquishment and potentially re-allocation of spectrum through ALF will occur at the margin, the ALF value should reflect the market value of the incremental or marginal block, i.e. the increase in value for the marginally excluded operator if the block was re-assigned to them.

1.1.4 Determining market values from auctions

In an auction, operators may be willing to pay higher average prices for spectrum, than the corresponding incremental market value for a combination of reasons:

- An operator may be the highest value user of a given block of spectrum, in which case their private value will be greater than the market value;
- The spectrum may offer capabilities that mean that there is a 'coverage premium' attached to the first blocks of spectrum acquired; and
- Operators may be able to acquire packages of spectrum whose value is greater than the sum of the values of the constituent blocks if each was acquired individually, reflecting complementarities.

Setting ALFs based on average prices paid or on willingness to pay for the first "core" blocks of spectrum will therefore lead to risks of inefficiency as, at this price, operators may relinquish marginal spectrum for which there is no alternative higher value use[7].

Any analysis of the UK auction values should therefore ensure the estimates of market value for the purposes of setting ALF reflect the - market value of incremental spectrum rather than average market values across large packages or

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6 For example EE's and Vodafone's supplementary bids for a package of 2 A1 blocks and 2 C blocks differed by a factor of 2.

7 Ofcom Annual licence fees for 900 MHz and 1800 MHz spectrum consultation, paragraph A9.39-A9.17

operators' willingness to pay for spectrum which offers capabilities which are distinct from incremental ALF spectrum.

1.1.5 The appropriate increment

In order to determine the appropriate ALF, the appropriate size of the marginal block or increment of spectrum needs to be determined. This should reflect the minimum size that an operator may relinquish and/or an operator may acquire under the ALF regime.

The mechanics of the forward looking ALF regime and hence the appropriate increment for setting ALFs are not clear from the Consultation.

The current use of 900 spectrum is a combination of GSM and UMTS technologies which use 200 kHz and 5 MHz channels respectively. In the analysis below we have considered the marginal valuation of a 2 x 5 MHz block of spectrum in the 800 auction, as this is the smallest increment for which information is available[8].

8 The unit marginal valuation of smaller increments than 2 x 5 MHz would be expected to be lower as larger channels provide additional capabilities under both 3G and 4G technologies.

2 Structure of the UK Auction

Before analysing the bids and results of the auction it is helpful to understand the key characteristics of the auction. This provides the framework in which the auction data can be analysed, to extract information on market clearing prices. Of particular importance when determining whether the data provides information on market clearing prices is the impact of reserve prices on the auction outcome.

2.1 Relevant features of the Auction

Following the migration of terrestrial television services to DTT, Ofcom was directed to:

- assess likely future competition in markets for the provision of mobile electronic communication services after the conclusion of the award of 800 MHz and 2.6 GHz bands;
- in the light of that competition assessment, put in place appropriate and proportionate measures (which may include rules governing the auction) which will promote competition in those markets after the conclusion of the auction;
- hold an auction of the 800 MHz and 2.6 GHz bands as soon as reasonably practicable after concluding the competition assessment

The auction design reflected the relevant parts of this direction and Ofcom's view of its wider statutory duties.

2.1.1 Overall design

The UK auction was structured as a combinatorial clock auction CCA with a principal stage and an assignment stage. The principal stage set the allocation of spectrum between bidders in terms of blocks of spectrum while the assignment stage set out which particular blocks of spectrum were allocated. For the purposes of setting ALFs, Ofcom has only used results from the principal stage.

Whilst CCA auctions are a relatively complex form of auction they are considered to have a number of characteristics which make them attractive:

- They allow bidders to bid and acquire packages of lots efficiently without aggregation risks;
- They encourage 'truthful' bids from bidders in the principal round, allowing bidders to adjust their valuations to take account of information disclosed in the auction; and
- They discourage some forms of strategic bidding.

Over time the CCA auction format has been developed, taking account of empirical evidence from previous auctions, to minimise the risk of strategic bidding. However, as described below, Ofcom did not use a standard form CCA auction, but introduced an innovation: the 'opt in' stage, which decoupled bids from payments for opted in operators. This innovation could have weakened the incentives for one or more bidders to bid truthfully[9].

2.1.2 Competition assessment

A competition assessment was carried out by Ofcom, prior to the auction, which was used to inform the design of the auction. The competition assessment considered that it would be desirable to aim to maintain four national wholesalers in the provision of mobile services. Two instruments were put in place by Ofcom to ensure the auction met that objective:

- A cap on the total amount of spectrum any mobile operator could hold;
- A set of minimum portfolio packages (MPP), one of which would be reserved for H3G or a new entrant operator.

2.1.3 Opt in round

The principal stage of the auction consisted of three parts that took place in sequence:

- An opt–in round during which eligible bidders decided whether to make bids at the reserve prices for the MPP;
- Primary Bid Rounds where in each round operators made bids on lots at a given price, with the price increasing for each lot category until there was no excess demand for that category and until there was no excess demand for any lot categories;
- A Supplementary Bids Round, where bidders could submit a range of additional bids for packages in addition to bids in the Primary Bid Rounds.

The addition of an opt in bid round was an innovation which allowed Ofcom to set a spectrum "floor" for a certain class of bidder, i.e. ensuring that as long as at least one such class of bidder was willing to pay the reserve prices on a defined set of packages they would be guaranteed to win one of these packages at the reserve price. The opt-in round also affects the outcome of the auction, as it may

9 An Ofcom Director, Geoffrey Myers, has argued that H3G's bids were unlikely to reflect truthful bidding, see Myers, Geoffrey, Spectrum Floors in the UK 4G Auction: An Innovation in Regulatory Design (August 8, 2013). TPRC 41: The 41st Research Conference on Communication, Information and Internet Policy. Available at SSRN: http://ssrn.com/abstract=2239123 or http://dx.doi.org/10.2139/ssrn.2239123

have incentivised and allowed H3G to engage in strategic bidding for lots which it was very unlikely to win under the rules, but which would then affect the prices paid by other operators.

At the end of the principal stage the winners are determined as the set of bids which maximise the amount bid within the available supply of spectrum.

The prices paid by these winners are then determined by an algorithm based on a second pricing rule, i.e. prices reflect the opportunity cost of assigning packages of spectrum to a winning bidder rather than to the marginally excluded user. This feature of the auction is consistent with the notion of 'market clearing prices' although the prices reflect the opportunity cost of the whole package acquired rather than incremental blocks of spectrum. The algorithm used in the auction was the "Vickrey-nearest rule".

3 Reserve prices in the UK auction

3.1 General principles

Ofcom recognised that there were a number of reasons for setting a reserve price in the recent UK auction:

- To cover the incremental costs of clearing the spectrum to encourage better regulatory engagement on spectrum allocation issues;
- To dis-incentivise frivolous bidding;
- To shorten the auction process by setting a higher starting price; and
- To reduce the risk of strategic bidding by reducing the payoff of bidding strategies which attempt to deliver a collusive auction outcome, where expressed demand for spectrum, and hence prices for spectrum, is deliberately lowered.

In previous auctions Ofcom had recognised that the first three of these factors can be addressed by setting a reserve price which is still significantly below the expected market value. To reduce the risks of strategic bidding it may be appropriate to set reserve prices at a higher level, closer to the market value of spectrum. However, Ofcom recognised that there were a range of potential efficiency losses from setting reserve prices too high and that there is a possibility that reserve prices will affect the auction outcome in ways which reduce efficiency overall. When determining reserve prices Ofcom considered six risks that needed to be balanced:

- the risk that a potential fourth national wholesaler (or opted-in bidder) is unable to obtain the reserved spectrum in the auction because of an excessive reserve price, when it would have been in consumers' interest for that party to obtain the spectrum ("risk (i)");
- the risk that an opted-in bidder obtains the spectrum when it would have been in consumers' interests that the opted-in bidder did not win the spectrum, because it has a much lower intrinsic value than the parties that would otherwise have obtained the spectrum ("risk (ii)");
- the risk of inefficiently unsold spectrum because reserve prices are set above the willingness to pay of the marginal bidder for the last lot in any spectrum category ("risk (iii)");
- the risk of strategic demand reduction which involves bidders reducing their demand at the margin, to pay less on infra-marginal units won: this may result in an inefficient allocation of the spectrum ("risk (iv)");

- the risk of tacit collusion among bidders to reduce demand in the auction to lower prices paid when this results in some spectrum not being acquired by the party that values it most ("risk (v)");
- the risk that a set of reserve prices that does not reflect the relative value of different bands of spectrum will distort the choice of the package for the reserved spectrum and may also reduce spectrum efficiency ("risk (vi)").

These risks reference the possibility that the auction outcome could be sub-optimal in terms of the allocation of spectrum between operators. Ofcom did not consider dynamic effects related to the prices paid by successful bidders in the auction in the auction. In particular, Ofcom did not consider the potential risk of setting the reserve price above a market clearing price but below the marginal operator's willingness to pay ("private value") which it has acknowledged will lead to a reduction in dynamic efficiency[10]. As a result, the reserve prices, even if they were optimal in terms of ensuring an appropriate allocation of spectrum, may not have been optimal in terms of setting the appropriate price of spectrum, either for the auction itself or as a benchmark for the determination of ALF.

3.2 Application of reserve prices

Ofcom had to take a number of decisions on the application of reserve prices in the auction including:

- The role of reserve prices in setting the price paid by opted in bidders.
- The structure of reserve prices;
- How the reserve prices would be used when determining eligible bids in the supplementary round; and
- How reserve prices would be used in winner and price determination.

These choices should have had an impact on the level of reserve prices, taking into account the balance of risks set out above. How the reserve prices were implemented also critically determines the degree to which either the final results of the auction or the underlying bid data can be used to estimate market clearing prices.

3.2.1 Reserve prices for opted in bids

Eligible bidders were able to make bids in the opt-in round at the level of the reserve prices for defined packages of spectrum. As H3G was the only opted in

10 Ofcom Annual licence fees for 900 MHz and 1800 MHz spectrum consultation, paragraph A9.39-A9.40

bidder they were able to acquire one of the three packages available to them at the reserve price for that package.

3.2.2 Structure of reserve prices

Ofcom chose to use 'linear' reserve prices, i.e. the unit reserve prices for each block of spectrum in a lot was constant with the reserve prices for packages determined by multiplying the number of blocks in the package in each lot by the unit price for this lot.

3.2.3 Eligible bids

In the rounds of consultation Ofcom proposed to allow all bids in the supplementary round where the bid for the package exceeded the reserve price for the package (subject to the constraints resulting from bidding in the primary round). This would have allowed bidders to submit package bids where the differential between bids was less than the differential in reserve prices between the packages, e.g. if the packages differed by one block the bid differential could be less than the corresponding reserve price for that block. However in the final decision, it was decided to apply the reserve prices on a 'lot by lot' basis, i.e. for any pair of bids, the difference in the bids had to be greater than the difference in the reserve prices for the packages.

This change has a significant impact on the usefulness of the bid data for determining market valuations, as no direct information is provided on operators' marginal valuations for blocks where these are less than the corresponding reserve price.

3.2.4 Reserve prices in winner determination and pricing

The reserve prices were used in bidder determination, i.e. national bids for each and every block at the reserve price. In theory, spectrum could have been unassigned, even if there was a valid set of bids for all of the auctioned spectrum, if there were other bids for a subset of spectrum which, combined with the reserve price "bids", had a higher aggregate value. In practice the auction cleared, with all spectrum being assigned to operators.

The prices paid by operators were based on a Vickrey nearest algorithm. This used the same winner determination methodology to determine the opportunity costs associated with each winning operator. Again the reserve prices were used as potential alternative bids in the calculation of this opportunity cost.

3.2.5 Effect of the reserve prices

The implementation of reserve prices had the potential to adversely affect bidder behaviour and the level of prices as the winner and price determination was implemented as if the government effectively acted as an additional bidder, bidding on all possible packages of spectrum at the reserve prices. In the most

extreme case this could have resulted in spectrum not being allocated, even if there were combinations of bids from the operators which were above the reserve price and which would have resulted in all spectrum being allocated to operators and higher revenues for the government.

3.3 Determination of reserve prices

3.3.1 DotEcon/Aetha report

In order to determine the reserve prices Ofcom, commissioned a report from DotEcon/Aetha to collect information on the "market value" of spectrum and to produce a recommendation on the appropriate level of reserve prices.

Three sources of information were used in the report:

- Benchmarking based on bid data and results from other auctions;
- Business modelling; and
- A panel of experts.

Benchmark prices

"Market value" was not explicitly defined by Ofcom or DotEcon/Aetha. But there are several reasons to think that the resulting values do not reflect market values:

1. The benchmarking exercise was "based on the demonstrated willingness to pay of bidders for comparable frequencies in similar situations"[11], i.e. based on information on operators' private values rather than on market clearing prices.
2. The analysis presented two sets of benchmarks for each spectrum band:
   - A small bidder benchmark; and
   - A large bidder benchmark.

The large bidder benchmark was based on the **average price paid** in auctions by the largest three operators in the market (whether or not there were additional operators in the market). Annex D provided examples of why this resulted in incentives to bid on a wide range of packages, under the assumption that reserve prices were applied on a package by package basis (which was then the proposed approach).

Applying reserve prices on a lot by lot basis however would restrict operators' ability to bid truthfully on all packages for which they had a positive valuation.

11 Executive summary of DotEcon/Aetha report

Even if two bids were submitted, where the difference between them is smaller than the reserve prices of the blocks by which the packages differ, the larger package could not possibly win, as a combination of the bid for the smaller package and government 'bids' at the reserve price will have a higher value. Rational bidders should therefore have suppressed such bids for the larger package, even where the total valuation of the larger package was greater than the sum of the respective reserve prices[12].

The small bidder benchmark was designed to capture the willingness to pay for smaller bidders, which was particularly important given that the reserve prices were used for the opt in bids. The small bidder benchmark was based on evidence on the willingness to pay by the smallest operator in four player markets or new entrants.

The report noted that in the German auction there was evidence that the fourth operator's willingness to pay for the first block of spectrum was approximately three times their incremental willingness to pay for a third block. Despite that, only an average willingness to pay was included in the benchmark calculations.

Figure 1. Benchmark values (GBP per MHz per capita)

	800MHz	1800MHz	2.6GHz paired	2.6GHz unpaired
Small bidder	£0.253-£0.434	£0.146-£0.219	£0.080-£0.121	£0.011-£0.059
Large bidder	£0.460-£0.714	£0.146-£0.219	£0.087-£0.121	£0.011-£0.059

Source: DotEcon/Aetha report

Financial modelling

Ofcom's financial modelling was based on a standard DCF approach. It is generally understood that valuations from such approaches are sensitive to a key number of assumptions. This is even more the case for valuations of marginal blocks of spectrum where it is difficult to accurately model the trade-offs between capacity, demand and quality of service resulting from marginal changes in spectrum. In general simplifying assumptions are used, for example that the level of demand is independent of spectrum holdings.

Tables 13-18 of the DotEcon/Aetha report present both absolute valuations for packages and some differentials between packages. Only a small number of potential spectrum packages for each were modelled with the selection of packages made before the transfer of 1800 spectrum from EE to H3G (which

makes many of the packages modelled irrelevant). Because of this there is limited information on operators' implied valuations of incremental spectrum in the auction based on the modelling.

However, the results of the modelling provide evidence that the reserve price eventually chosen for the A1 blocks was close to operators' estimated marginal values for these blocks from the modelling, for example

- All EE's incremental values for a single additional 800 block (going from 2x5 to 2x10) are barely above the £225m reserve price. Their incremental value for a second additional 800 block (going from 2x10 to 2x15) is far below reserve price.
- Given that H3G had acquired 2x15MHz of 1800 just before the auction, their incremental values for additional 800 became similarly low. The H3G value for a **single** 800 block - from 0,15,10 to 5,15,10 - is not much above the reserve price, except in scenarios where H3G anticipate a large growth in market share and the value for a second incremental block appears to be below the reserve price[13].

Given that O2 and VF, who had relatively high marginal valuations of 800 spectrum from the modelling exercise, were constrained by spectrum caps from acquiring all of the spectrum, the marginal values for EE and H3G could have been assumed to set the incremental market clearing price in the auction. While it is difficult to be conclusive, due to the limitations in terms of the packages modelled, the modelling results are consistent with the hypothesis that the reserve price was set above the market clearing price.

Recommended reserve prices

The reserve price recommendation made in the Aetha/DotEcon report was based on an assessment of risks similar to that set out by Ofcom with a focus on setting prices as high as possible (to discourage strategic bidding) whilst not choking off demand. Thus the focus was on setting prices below the private value of at least one bidder rather than setting the price to reflect the opportunity cost of excluded bidders, i.e. the market clearing price.

The report recommended a reserve price of £217 million for the A1 blocks.

3.3.2 Assessment of Ofcom's derivation of reserve prices for 800 spectrum

Ofcom set the reserve price for A1 blocks at £225 million in the auction, higher than the value recommended by DotEcon and Aetha.

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13 The relevant delta from 5,15,0 to 10,15,0 is not shown, but can be estimated using the delta from 5,15,10 to 10,15,0 and the fact that the business model appears to assign little value to just 2x10 MHz of 2600 spectrum. This delta is variously (1347-1230), (2309-2183), (1437-1351), (2309-2183), (2855-2743), (4694-4685) all of which are well below the 225m reserve price.

There sources and methods used by Ofcom to set the reserve price resulted in a significant risk that the reserve price for A1 blocks could be above the market clearing level:

- The level of reserve prices was determined without reference to the risk that the resulting prices would be set above the market clearing price.
- Ofcom appears to have given significant weight to reducing the pay offs for price minimising strategic bidding, and as such, set prices as high as possible subject to these prices being below the willingness to pay of bidders.
- The recommendations were based on the assumption that reserve prices would not be applied on a lot by lot basis, but on an aggregate level – which was the proposed approach at the time.[14] For this reason the recommendation was based on average prices, rather than marginal prices. There is no indication that the results of the analysis were revised to take account of the subsequent change to lot by lot reserve prices in the final auction rules.
- The benchmarking approach which was used to inform Ofcom's determination of the reserve prices was based on information on operators' willingness to pay in other 800 auctions, potentially including any coverage premium associated with the first block of low frequency spectrum suitable for LTE.
- The financial modelling did not cover a wide enough range of packages to provide robust estimates of market clearing prices, particularly given that many of the packages modelled were irrelevant by the time of the auction, given the transfer of 1800 spectrum from EE to H3G. The information that was available is consistent with reserve prices for the A1 block being above a market clearing price.

In addition the application of reserve prices on a 'lot by lot' basis means that there is an increased probability that reserve prices would influence winner and price determination.

In the next section we analyse the results of the auction in the light of the above analysis.

14 Paragraph 254 of the report

4 Information on incremental valuations from the auction

Incremental market clearing prices are a function of all operators' incremental valuations for spectrum. A necessary condition for the UK auction data to provide a robust estimate of l market clearing prices is that the data shows relevant operators' valuations of incremental spectrum. In this section we assess the degree to which such information is available from the UK auction.

4.1.1 Incremental valuations below reserve prices not available

As noted above, Ofcom chose to implement reserve prices on a lot by lot basis, specifically to prevent operators acquiring incremental spectrum at prices below the reserve price[15]. The result of this rule is that if operators were bidding to reflect their true willingness to pay, where their willingness to pay for an additional block is below the reserve price, one or other of the relevant bids would not have been submitted.

As a result information on operators' marginal willingness to pay, where this is less than the reserve price, will not be directly observable from comparisons of bids.

4.1.2 Marginal valuations for spectrum above the spectrum cap not shown

The auction rules also did not allow operators to bid for spectrum above their spectrum caps. To the extent that spectrum caps were a binding constraint this means that the full unconstrained marginal valuations of spectrum were not available.

4.1.3 Strategic bidding

While CCA auctions are designed to reduce the incentives and ability for strategic bidding, there is still scope for some strategic bidding for example:

- Not bidding for all possible combinations of spectrum in the supplementary bid round,;
- Bidding strategically with the aim to increase prices paid for other bidders, where there is a belief that other bidders are capital constrained and as such increasing the price paid by them could reduce their ability to compete.

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15 Assessment of future mobile competition and award of 800 MHz and 2.6 GHz Statement Publication date: 24 July 2012 Paragraphs 7.35-7.36

This could result in a combination of some information on marginal valuations not being available, because operators have not submitted complete bids, or some bids not being fully revealing of operators' intrinsic valuations.

4.2 Evidence on 800 marginal valuations from the UK auction

4.2.1 Vodafone and Telefónica

Due to the low frequency spectrum caps, Vodafone and Telefónica were not able to bid on more than 2x10 MHz of 800 spectrum in the auction. In the event, Vodafone and Telefónica chose not to bid for any packages which contained less than 2 x 10 MHz of spectrum at any point in the auction.

For this reason no direct information on Vodafone or Telefónica's valuation of incremental 800 MHz spectrum can be derived from the auction.

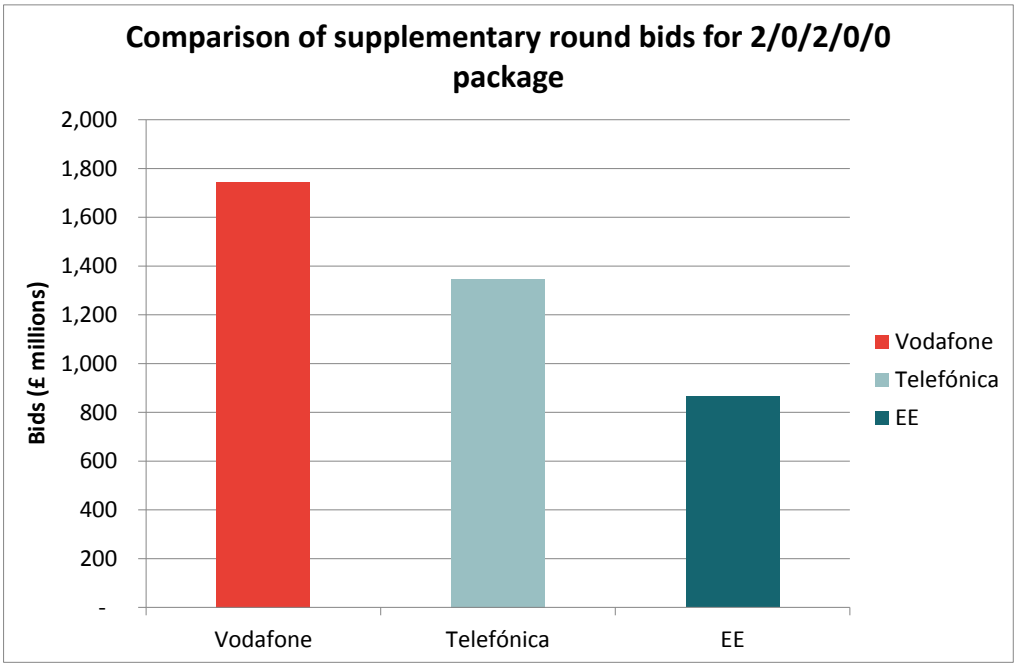
Both bidders expressed very high valuations for 2 x 10 MHz spectrum, reflecting specific factors:

- No existing spectrum suitable for LTE coverage deployment with at least 2x 10 MHz bandwidth;
- Existing coverage grids and a network sharing agreement predicated on the availability of low frequency spectrum.

Vodafone's and Telefónica's bids were much higher than other operators' bids for similar spectrum, as shown in Figure 2.

Information on incremental valuations from the auction

Figure 2. Comparison of bids for similar packages



Source: Frontier Economics analysis of bid data

This information on average private values for 800 MHz spectrum will not be indicative of market values for 800, much less 900 MHz, spectrum. As such Telefónica's and Vodafone's bid data provides no useful information for the purposes of ALF determination.

4.2.2 H3G

H3G was the opt-in bidder. As a result H3G was guaranteed to be able to win one of the MPPs at the reserve price. This provided it with two incentives other bidders did not have:

- To the extent its calculated pay off for one MPP was higher than the other, it had an incentive to influence other bidders' bids in order to increase the probability of securing the MPP with the highest pay off (or a package containing this MPP); and
- As it did not pay the full auction value for the MPP acquired, to the extent it believed other bidders were or could be capital constrained, it had a higher payoff for strategies designed to increase prices paid overall.

Information on incremental valuations from the auction

As indicated earlier[16], H3G was considered to have followed a strategy in the supplementary rounds designed to ensure it acquired one or other of the MPPs at the reserve price, rather than attempting to maximise their pay off.

H3G may have had an incentive to also bid strategically in the Primary Rounds in order to either increase overall prices paid or influence relative prices between bands in order to increase their probability of acquiring the MPP with the highest pay off (at the reserve price)[17].

In a CCA auction there are risks to such a strategic bidding approach. However these risks can be minimised by bidding on large packages of spectrum when demand overall was high, as other operators are likely to have high willingness to pay for an initial block of spectrum, and by dropping demand for lots rapidly in rounds when demand moved closer to supply. An operator engaged in such a strategy would then move to bids reflecting their own valuations when demand and supply were aligned.

H3G behaviour in the primary rounds appears consistent with such a strategy with H3G initially bidding for 2x15MHz and 2x10MHz 800 spectrum in conjunction with packages of 2x70 MHz (or more) of 2.6 GHz spectrum, and then dropping down to a MPP when demand for 800 blocks matched supply. H3G's bids in the supplementary round are also consistent with such a bidding strategy, with no bids for large packages other than those carried over from the principal round, which also included a large quantity of C blocks.

We conclude that H3G's bidding in the primary rounds is unlikely to provide a realistic indication of H3G's true valuation for incremental 800 spectrum[18]. The lack of any other bids for packages containing a higher amount of 800 spectrum, other than the MPP packages, in the supplementary round indicates that H3G's valuation of spectrum was lower than the reserve price.

As such H3G's bid data appears to provide no useful data information for the purposes of ALF determination.

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16 Myers, Geoffrey, Spectrum Floors in the UK 4G Auction: An Innovation in Regulatory Design (August 8, 2013). TPRC 41: The 41st Research Conference on Communication, Information and Internet Policy. Available at SSRN: http://ssrn.com/abstract=2239123 or http://dx.doi.org/10.2139/ssrn.2239123

17 By following a strategy designed to ensure that they only paid the reserve price for one of the MPPs, H3G would not have been able to directly influence the package they acquired, which would have been dependent on other operators' bids for packages including this spectrum. Thus only by influencing other operators' relative valuation of packages could H3G indirectly influence its pay off.

18 Ibid. Geoffrey Myers notes "Although these were H3G's highest bid amounts, they were for such large packages that effectively these 4 bids […] were not relevant in influencing the winning outcome or prices."

Information on incremental valuations from the auction

4.2.3 EE

Available bid data

EE submitted a wide range of bids in the supplementary round with varying amounts of 800 spectrum in combinations of A1 blocks (5 MHz paired) and the A2 block (10 MHz paired with a coverage obligation).

Bids were made on 5, 10 and 20 MHz of paired spectrum but no bids were made on packages containing 15 MHz paired of spectrum (either 3 A1 blocks or 1 A1 block and the A2 block). Assuming EE bid truthfully, this indicates that EE had valuations above the reserve price for a first, second or fourth[19] 5 MHz block of 800 spectrum, but the valuation of a third 5 MHz block of spectrum was below the reserve price and as a result not bids were submitted for 15 MHz of spectrum.

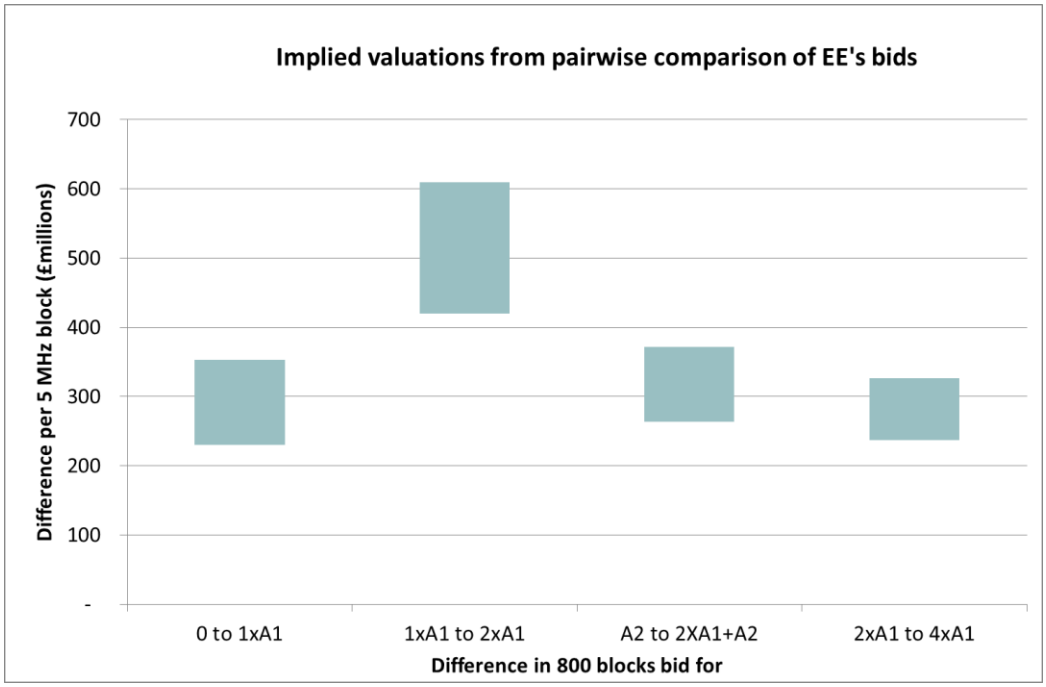
A pair wise comparison of packages which only differed by the number of A1 blocks gives an indication of the valuations for incremental 800 spectrum[20].

The results are summarised in the chart in Figure 3:

19 While the incremental value from a third block to a fourth block is not observable, the fact that the incremental valuation from two to four blocks was above the corresponding reserve prices while the incremental valuation from two to three blocks was below, indicates that the incremental valuation for the fourth block must be above the reserve price.

20 Given the coverage obligation attached to the A2 block, and the fact that the spectrum was packaged in a single 10 MHz paired block, means that analysis of pairs of bids for packages differing by only this block are unlikely to add useful information.

Figure 3. Results of pairwise comparison



Source: Frontier analysis of auction data

Existence of a premium

In general the difference in EE's bids is close to the reserve prices for the spectrum with the exception of relatively high incremental valuations from 2x5 MHz to 2x10 MHz. This valuation appears to be consistent with the existence of a premium attached to having 10 MHz of contiguous spectrum for LTE.

The high EE bid for the second block may also reflect strategic value: if EE won 2x10 MHz, and they believed that there was a contiguity premium[21] they may have expected only two other bidders (e.g. Vodafone and Telefónica) to win 2 x 10 MHz as well, and a fourth (e.g. H3G) to be excluded from 800 MHz spectrum.

The existence of such a premium is also indicated by the apparently higher valuation placed by EE on the 4th block of 800 spectrum than the (implicit) EE valuation of the third block of spectrum. Again the 4th block will have a premium

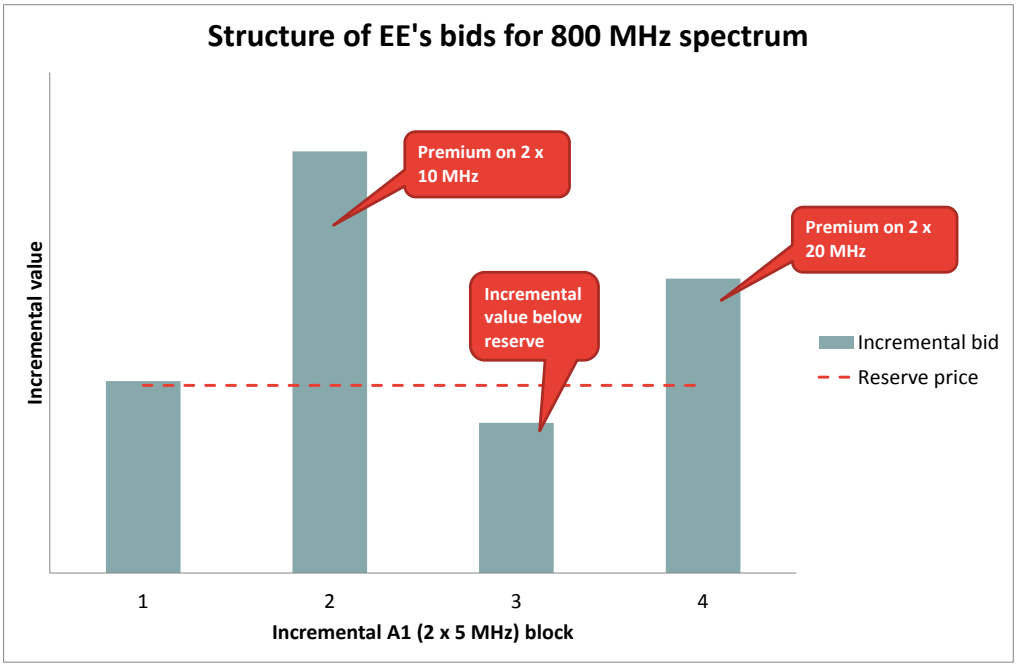
[21] If EE believed that other operators' valuations did not put a premium on 2x10MHz blocks then there would be little reason for 2x10MHz to have particular strategic value compared to say 2 x 15 MHz, where there is no observable premium.

Information on incremental valuations from the auction

related potentially to an ability to deploy 20 MHz carriers in LTE, along with further strategic value[22].

Figure 4 below illustrates the apparent structure of EE's bids.

Figure 4. Illustration of structure of EE's bids



4.3 Conclusion

A combination of the auction rules and operators' bid strategies means that the auction data provides only partial information of operator's incremental private values. In particular:

- The auction design and the relatively high reserve price for 800 spectrum suppressed information on incremental values, with H3G not making any supplementary bids for 800 spectrum in addition to their opt-in bids;
- Telefónica and Vodafone were prevented by spectrum caps from bidding for more than 10 MHz of 800 spectrum and chose not to bid for 5 MHz of 800 spectrum.

[22] If EE had won 4 A1 blocks, then only one other bidder would have been able to win 800 MHz spectrum (the A2 block), an outcome which would be damaging to at least one of Vodafone or Telefonica, as well as probably excluding H3G.

Only EE provided bids on a wide range of packages containing varying amounts of 800 spectrum. Before these data can be relied upon to derive market value estimates for the UK, the following factors need to be considered:

- No bids for 15 MHz of spectrum, presumably due to the marginal value being below the reserve price;
- Relatively high valuations of multiples of 10 MHz of 800 spectrum suggesting that EE placed a premium on 10 MHz of contiguous spectrum; and
- The fact that EE's bids for large volumes of 800 spectrum may have had strategic intent.

The second and third factors relate directly to the revealed value of the specific spectrum being auctioned in the context of an auction. As the spectrum subject to ALF is likely to be available in smaller increments and is unlikely to have strategic value, these factors should be discounted when assessing the appropriate level of ALFs.

Information on incremental valuations from the auction

5 Estimating market values

The previous section indicates the information from the UK auction on operators' incremental valuations of 800 spectrum is partial and as a result it is not possible to definitively derive the market clearing value from the auction. The UK auction is however still the most important source of information for the value of spectrum in the UK, given the limitations of other sources of information available (such as benchmarking and modelling). It is therefore appropriate for Ofcom to extract as much relevant information as possible from the auction data. Ofcom can then place appropriate weight on any resulting estimates given the known issues with the underlying data.

In this section we derive the most appropriate estimates of the market value of 800 MHz spectrum from the UK auction, addressing the issues identified earlier. We start by reviewing the outcome of the UK auction and then review the two methods proposed by Ofcom to estimate the market price of 800 spectrum:

- Linear Reference Prices (LRP) which is Ofcom's preferred methodology; and
- The Additional Spectrum Methodology (ASM) which was proposed prior to the Auction.

We conclude that the methodologies proposed by Ofcom suffer from flaws that mean that the resulting estimates of market value are not reliable. In light of this, we develop and apply an approach which enables the derivation of the best estimate possible of the value of spectrum based on a detailed analysis of the bid data

Before analysing the bid data to derive an appropriate estimate of UK market value, we consider the relationship between the reserve price and market value, in the light of the analysis presented earlier. This concludes that the reserve price for 800 spectrum in the UK auction is the upper bound for the market value of such spectrum in the UK.

Relationship between reserve price and market value

Table 1 summarises the outcome of the UK auction principal stage.

Table 1. Results of the principal stage

BIDDER	A1	A2	C	E	Price paid (£)
Vodafone	2	0	4	5	790,761,000
Telefónica	0	1	0	0	550,000,000
EE	1	0	7	0	588,876,000
H3G	1	0	0	0	225,000,000
Niche	0	0	3	4	186,476,000
Totals	**4**	**1**	**14**	**9**	**2,341,113,000**

Source: Ofcom

The derivation of these prices is show in Annexe 1.

5.1.1 Impact of 800 reserve prices on the auction results

The analysis in Annexe 1 indicates that for all bidders for 800 spectrum the reserve price for A1 blocks influenced the price paid:

- For EE, Vodafone and Telefónica the set of bids used to estimate the 'opportunity cost' of the package awarded to that bidder did include the reserve prices for 800 MHz spectrum;
- H3G paid the reserve price for the one block of 800 spectrum they acquired with an opt-in bid.

The inclusion of reserve price 'bids' for 800 spectrum in the calculation of the prices paid by Vodafone, EE and Telefónica shows that if all of the bids by this bidder had not been made some spectrum would have been unallocated at the reserve prices, i.e. that there was no bidder willing to pay more than the reserve price for this spectrum in the absence of one of the bidders. This demonstrates that the reserve prices for A1 spectrum were above the incremental market clearing price.

5.1.2 Conclusion

The results of the auction clearly demonstrates that the reserve price for an A1 block, that is £225 million, is above the market clearing price for incremental 800 spectrum, i.e. that the l market clearing price for 2x5 MHz of 800 spectrum must lie below £225 million.

Estimating market values

5.2 Ofcom's methodologies cannot be relied upon to derive market value

5.2.1 Linear Reference Prices (LRP)

Decomposition of auction results

The results of the auction provide package prices for each bidder but do not provide explicit values for each of the lots purchased within the package, either for individual bidders or for the bidders in aggregate.

The LRP methodology estimates a set of linear prices for lots which best fits the prices paid by operators in the auction. This means that the LRP prices are a decomposition of the Vickrey prices paid by bidders in the auction. As the prices paid in the auction under the Vickrey rule should, in theory, reflect opportunity costs then the LRP estimates should also reflect opportunity costs.

Ofcom have not clearly set out why the results of the LRP methodology should be a good estimate of the market clearing price for individual bands given the combinatorial nature of spectrum valuations.

Applying the LRP methodology to the UK auction data

As mentioned above, the inclusion of reserve price 'bids' for 800 spectrum in the calculation of the prices paid by three of the operators shows that if all of the bids by this bidder had not been made some spectrum would have been unallocated at the reserve prices. This indicates that the reserve prices for 800 spectrum were above the market clearing price.

Market clearing prices represent opportunity costs for winning bidders, namely the alternative value which other bidders would gain from that spectrum. However, at the level of the 800 reserve prices in the auction there is not sufficient demand in the absence of one bidder, for example Vodafone, and 800 spectrum would have been unsold.

If the prices paid in the auction do not represent true opportunity costs then it follows that the LRPs also do not reflect opportunity costs. LRPs do not reflect market values.

Demonstration that Ofcom's LRP is above the market clearing price

It is straightforward to demonstrate that Ofcom's LRP-derived estimate for 800 MHz spectrum (268.5m for an A1 block) *must be* above market value. The reason is that re-running the winner and price determination with an A1 reserve price set just above £254m (rather than £225m) leads to unsold 800 MHz spectrum as illustrated below. Since a market clearing price must be a price at which all

spectrum sells (with none retained by the auctioneer), this shows that the results of the LRP methodology cannot be the incremental market clearing price.

Table 2. Hypothetical outcome with reserve prices set at £254 million

BIDDER	A1	A2	C	E	Opportunity cost (£)
Vodafone	2	0	4	4	817,761,000
Telefonica	0	1	0	0	579,000,000
EE	0	0	8	0	418,376,000
H3G	1	0	0	0	254,001,000
Niche	0	0	2	5	158,000,000
Unsold	1	0	0	0	-
Totals	**4**	**1**	**14**	**9**	**2,227,138,000**

Source: Frontier analysis of Ofcom bid data

LRP excluding reserve prices

In its report to Ofcom, DotEcon note that the reserve prices influence the prices paid and hence the LRP. As an alternative scenario, DotEcon ran the Vickrey price rule with unallocated spectrum valued at zero, i.e. the reserve prices did not contribute to the calculation of the Vickrey prices.

Clearly this is a hypothetical scenario, as with a lower reserve price we would expect to see additional bids which would affect the auction outcome. In addition changes to the reserve prices may have affected H3G's bid strategy as H3G's pay offs would have changed.

Table 16 of the DotEcon report shows that the removal of the reserve prices lowers the resulting Vickrey prices for all three operators where the reserve prices were inputs in the prices paid in the final auction. However the impact was not uniform:

- The impact on Vodafone's and Telefónica's Vickrey prices was limited as reserve price bids were substituted by combinations of bids which included EE's bids for additional 800 spectrum[23]; and

23 These bids include a considerable contiguity premium.

Estimating market values

- The impact on EE's Vickrey prices was substantial as, in the absence of reserve price "bids" there were no credible alternative bids for the 800 spectrum acquired by EE.

This difference means that when the LRP methodology was applied to these Vickrey prices, with H3G's price set to be the reserve price, the resulting fit was very poor with very large excursions[24]. This poor fit to the results based on actual bids by operators in the auction (once the reserve price "bids" are excluded) indicates that the underlying assumption that there is a reasonable linear decomposition of the price paid does not hold.

Conclusion on LRP

Ofcom's preferred LRP method produces results which are demonstrably above the incremental market clearing price reflecting a combination of:

- inherent weaknesses in the LRP method which means that it does not reflect incremental market clearing prices; and
- the inclusion of the (above clearing price) reserve prices in the calculation of Vickrey prices in the auction.

Removing the effect of the reserve prices from the LRP calculation produces significantly lower estimates but the large excursions show that these estimates are not a good approximation of market clearing prices for each band.

5.2.2 The Additional Spectrum Methodology

The ASM methodology attempts to estimate the market price for spectrum by calculating the additional value resulting if hypothetically additional blocks of spectrum had been available in the auction but bids remained the same. The ASM methodology could produce estimates of market value for low frequency spectrum to the extent that bids in the auction reflected the truthful value of generic "low frequency" spectrum to bidders.

In practice bids were made on the basis of the specific spectrum available in the auction rather than the hypothetical case that additional generic spectrum was available.

Application to the UK auction data

When applied to the UK auction, the results of the ASM show large variations in estimated 'marginal' (incremental) valuations. This reflects the nature of the UK auction data:

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24 As shown in table 18 of the DotEcon report and as illustrated by the significant change in values if the revenue constraint was dropped.

- other than EE, the operators' bid data did not show any information about their valuations of incremental spectrum, above the spectrum they gained in the auction; and
- the structure of EE's implied incremental valuations in the bid data reflect the specific characteristics of the spectrum available in the auction.

As a result of these effects, estimates from the ASM methodology are extremely unreliable, and provide very little evidence about what bids would have been made for 900 MHz spectrum, if it had hypothetically been included in the auction. It appears that Ofcom agree with our assessment that ASM is unreliable [Paragraph 4.24 of the consultation states that it is "highly sensitive to the underlying assumptions"].

In light of these deficiencies, it is unreasonable for Ofcom to include ASM results in its sensitivity analysis to determine a plausible range of values (see Figure A8.13) as the higher end of the range is clearly above a market clearing price for 800 spectrum. The effect of adding the ASM results is to suggest the LRP estimate is somewhere in the middle of a range of plausible estimates, whereas without these ASM points it becomes clear that the LRP is right at the top of the range of estimates.

5.3 The appropriate approach to derive the value of 800 spectrum from UK auction data

5.3.1 Available data on incremental valuations

As explained above the methods set out by Ofcom cannot be relied upon to derive robustly estimates of the market value of 800 spectrum from the UK auction.

As noted above:

- Vodafone and Telefónica only submitted bids with 2 x 10 MHz of 800 MHz spectrum, revealing their average value of 10 MHz of spectrum but no information about their valuations of additional incremental (i.e. smaller) blocks;
- H3G only submitted bids for multiple blocks of 800 MHz spectrum in packages in conjunction with very high volumes of 2.6 GHz spectrum, which it had very low probability of winning. These bids reveal strategic intent and are not therefore informative about the true value of incremental spectrum to H3G. H3G did not bid on a wide range of 800 MHz packages in the supplementary round, suggesting that its true incremental valuation was lower than the reserve prices;

- None of the new entrants bid for 800 MHz spectrum at all, indicating that their valuations for 800MHz were also lower than the reserve price.
- Only EE bid on a wide range of packages with differing amounts of 800MHz spectrum. As the largest operator, and one which had already deployed LTE, it is likely that EE's bids include some strategic value in excluding other operators from LTE spectrum.

As a result the EE bid data is the only useful data on valuations of incremental spectrum available from the auction. Given the limitations of other bids and data sources, these valuations should be given most weight in Ofcom's determination of the level of ALF. However to understand the weight that should be given to the data it is necessary to examine the degree to which these valuations are a robust estimate of incremental market clearing values.

5.3.2 Assumption that EE is the marginal excluded bidder

The bid data could be used to estimate the market clearing price if it is assumed that EE is the marginal excluded bidder for low frequency spectrum, i.e. if two conditions are met:

- The current allocation of low frequency spectrum is such that the holders of spectrum are the highest value users of spectrum; and
- If additional spectrum was made available from one of the other operators, EE would have the highest valuation of this spectrum.

If the current allocation was not optimal, in terms of spectrum being allocated to the highest value users, then potentially some of the spectrum would be optimally allocated to EE and one of the other operators would be the marginally excluded user. In this case EE's valuation would potentially overestimate the market clearing price for the spectrum, as EE would be the 'first price' bidder and another operator's valuation would set the 'second price' or opportunity cost for the spectrum.

If another operator, who was not the current holder, had a higher valuation for spectrum than EE then their valuation would set the opportunity cost for this spectrum and hence EE's valuation would underestimate the market clearing price for the incremental spectrum.

We now examine whether the available evidence is consistent with the hypothesis that EE is the marginal excluded bidder.

Assumption that spectrum is currently allocated to the highest value users

It is reasonable to assume that low frequency spectrum is allocated to the user with the highest valuation:

- 900 spectrum is currently allocated to Telefónica and Vodafone, both of which have significant sunk costs associated with this frequency and are rolling out WCDMA networks using 900 to deliver voice and data; and
- the 800 spectrum was generally[25] allocated to the highest value bidders in the auction.

Assumption that EE is the highest value excluded bidder

From the bid data in the auction it is clear that EE's valuation of 800 spectrum is higher than H3G's or a new entrant bidder.

The question is then whether Vodafone or Telefónica would have a higher valuation of low frequency spectrum released by Telefónica or Vodafone respectively than EE.

Both Vodafone and Telefónica hold 27.4 MHz of paired low frequency spectrum (10 MHz each of 800 acquired in the auction and 17.4 MHz of 900 spectrum) compared to 5 MHz for EE. Given that it is reasonable to expect marginal valuations of low frequency spectrum to decline with spectrum holdings, it is reasonable to assume that EE would have the highest valuation of any low frequency spectrum made available.

In light of the above, and whilst the nature of the auction does not allow a definitive assessment of the marginal value of low frequency spectrum for Vodafone and Telefónica, the analysis of the available evidence is consistent with EE's valuations of incremental spectrum setting the market clearing price.

5.3.3 The need to adjust EE's bid data for specific factors

The bid data that is available from EE reflects the specific nature of the 800 spectrum available in the auction and may also include elements of strategic bidding.

The clearest issue with the EE bid data is the premium for 2x 10 MHz of spectrum compared to 2 x 5 MHz of spectrum which can be observed in:

- Higher marginal valuation from 1 to 2 A1 blocks in the auction than from 0 to 1 A1 block;
- No bids by EE for 3 A1 blocks, indicating that the marginal value for a third block is less than the reserve price, but with bids for 4 A1 blocks showing a large marginal valuation from 2 to four blocks.

25 Subject to the competition constraints

Both of these observations imply that EE value blocks giving multiples of 2 x 10 MHz (i,e, from 1 to 2 and from 3 to 4 blocks). This premium is likely to reflect some combination of:

- The higher maximum user bandwidth with 10 MHz and 20 MHz carriers; and
- Strategic value in preventing other MNOs acquiring spectrum in the auction for rolling out LTE at low frequencies.

In addition, EE's bids for a single block of 800 spectrum will reflect a 'coverage premium' attached to the first block of low frequency spectrum. This first block will provide coverage, using EE's existing grid of sites, over and above that available from higher frequency spectrum. However additional low frequency spectrum will not provide significant additional coverage.

Any premia for EE corresponding to these three factors would not apply to generic low frequency spectrum, for example the 900 MHz spectrum as:

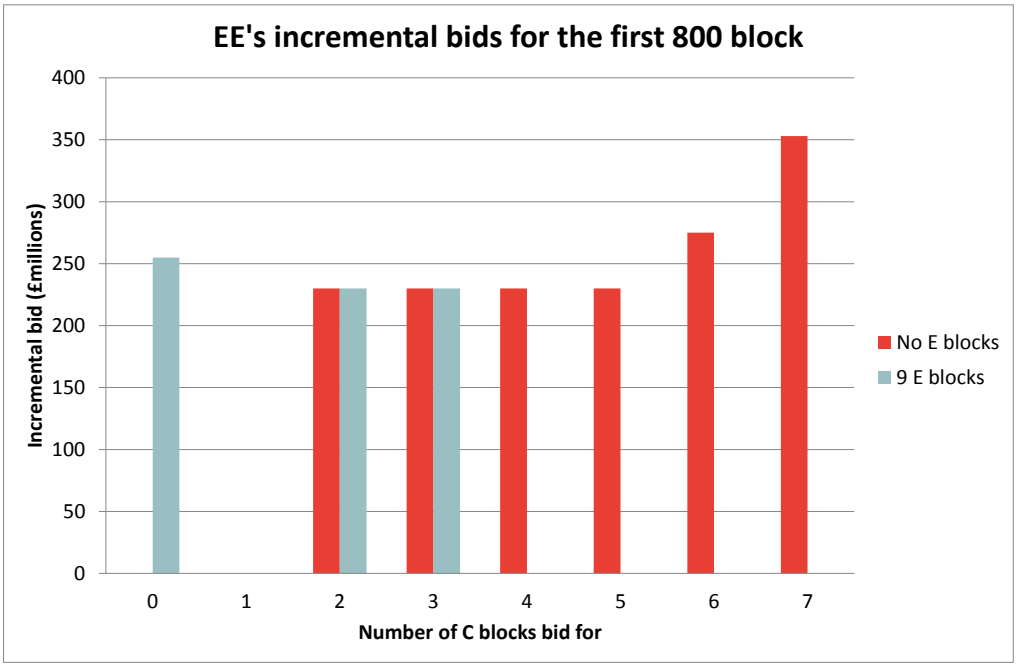
- Spectrum available under ALF would be unlikely to include 2 x 10 MHz of contiguous spectrum;
- All other MNOs now have low frequency spectrum allowing for LTE roll out, so acquiring marginal blocks of 900 spectrum will not have strategic value in denying other operators the ability to roll out; and
- There will be no additional coverage premium attached to additional blocks of low frequency spectrum.

5.3.4 Using EE's valuation of a single block of 800 spectrum

Analysis of EE's valuation for a single block of 800 spectrum provides value because that bid data will not be affected by any premium for 2x10 MHz of 800 spectrum.

EE's incremental bids for a single block of spectrum (i.e. the bid differential from 0 to 1 A1 blocks with the packages otherwise the same) ranged from £230 million to £353 million, with the incremental valuation varying depending on the other blocks contained in the pairs of packages. The range of valuations is illustrated in **Figure 5** below.

Figure 5. EE's bids for 1st 800 Block



Source: Frontier Analysis of Ofcom bid data

The chart shows that for most pairs of bids, the incremental value moving from zero to one block of 800 spectrum was £230 million, marginally above the reserve price.

In general it would be expected that the marginal value of spectrum would decrease as the overall package size increases, while the EE bid data shows increased bids for 800 spectrum when EE bids for large quantities of C blocks (paired 2.6 GHz spectrum). The higher bids for an incremental block of spectrum in conjunction with high volumes of 2.6 GHz spectrum is consistent with strategic value from either reducing the ability of other players to offer LTE services with the same bandwidth as EE or increasing the price paid by other players to acquire this spectrum.

As explained above, the first block of spectrum will also include some premium attached to the first block of low frequency spectrum. Taking account of this and discounting the higher incremental valuations associated with large volumes of 2.6 GHz spectrum, £230 million can be considered an upper bound for the value of additional 5 MHz blocks of 800 spectrum.

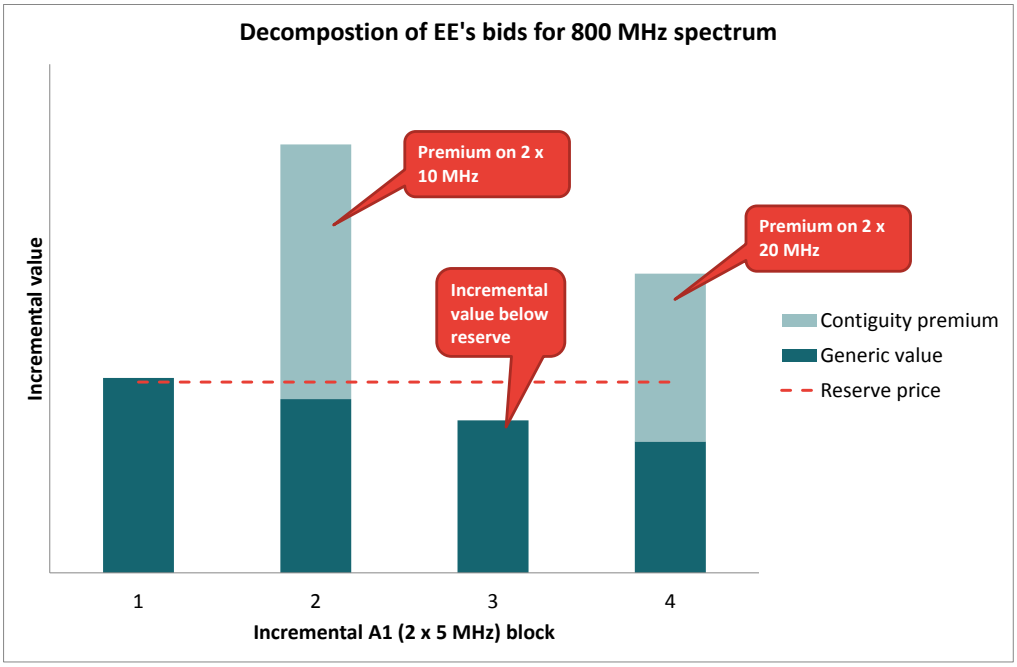
5.3.5 Valuation of additional blocks of 800 spectrum

However given that EE acquired 1 A1 block of spectrum in the auction, EE's valuation of an additional block of spectrum would be a better indicator of its marginal value of low frequency spectrum. Unfortunately because of the

premium attached to 2x10 MHz of spectrum, the EE bid data on its own does not provide a reasonable estimate of the value that EE would now place on an additional 5 MHz block of other low frequency spectrum[26].

In order to estimate the value of an additional 5 MHz block we need to carry out a decomposition of EE's bids into a generic spectrum valuation and a premium as illustrated in **Figure 6** below:

Figure 6. Illustrative decomposition of EE's valuation



In order to carry out the decomposition we used two methods:

- Method A assumes that the generic value of spectrum declines linearly and that the value of the premium is constant in absolute terms going from 1 to 2 blocks, as going from 3 to 4 blocks;
- Method B assumes that the generic value of spectrum declines linearly and that the value of the premium is a constant proportion of the total valuation in the overall value from 1 to 2 blocks as from 3 to 4 blocks.

The marginal valuations are estimated by comparing pairs of bids where only the number of A1 blocks bid for differ. Given the range of bids for 800 blocks,

[26] This premium also leads to the high upper end of the valuation range under the ASM methodology due to the high incremental bids by EE for an additional 5 MHz of low frequency spectrum 'released' by operators other than EE.

depending on the additional spectrum included in packages, we also used two sets of input data to the calculations:

- The mean incremental valuation across all corresponding bid pairs; and
- The median incremental valuation across all corresponding bid pairs.

Calculations based on mean values imply equal weight given to each observation, but these can be distorted by outliers, for example relatively high valuations for strategic reasons. Calculations based on median values should be more robust to outliers.

Full details of the calculations and input data are included in Annexe 2. The results are shown below.

Table 3. Implied valuation of second block of 800 MHz spectrum excluding premium

Method	Data	Result (£million)
Method A	Mean values	195
	Median values	179
Method B	Mean values	214
	Median values	198

Source: Frontier analysis of bid data (see annexe 2 for details)

The results of the decomposition appear plausible:

- As the values for a second block excluding the premium are below the reserve price the implied value of a third block is considerably below the reserve price for A1 blocks which is consistent with EE making no bids for packages including 3 blocks;
- The gradient and implied coverage premium is relatively shallow compared to other sources of information, for DotEcon's estimates of the relative valuations of the first and third block's by E-plus in the German 800 auction[27]. This suggests that the estimated gradient and resulting estimated valuations are, if anything, conservative.

27 Spectrum value of 800MHz, 1800MHz and 2.6GHz A DotEcon and Aetha Report for Ofcom July 2012 paragraph 87.

5.4 Conclusion

Ofcom's preferred LRP methodology clearly over-estimates the market clearing price of incremental 800 spectrum due to inclusion of high reserve prices in the calculation of Vickrey prices and the fundamental deficiencies of the LRP method as a form of estimating incremental market clearing prices.

There are two independent sources of information that provide robust estimates of an upper bound on the appropriate valuation of 5MHz paired 800 spectrum:

- The reserve price for an A1 block of £225 million; and
- EE's bids of £230 million for the first block of 800 spectrum.

While the lack of bid data from the auction makes it difficult to precisely determine the appropriate market clearing price, under a set of reasonable assumptions, the best estimate of the incremental market clearing price for 5MHz paired 800 spectrum to be used as a benchmark, is in the range £179 million to £214 million.

Annexe 1: Derivation of UK auction prices

Using the published auction rules, we can explain the base prices paid by winners in the auction by considering counterfactual auctions, where in turn each bidder is excluded[28].

The "opportunity cost" column in the tables below takes each remaining bidder's bid for the package won in the counterfactual auction and subtracts their bid for the package won in the real auction. (Note that these differences may be negative, or may reflect a value assigned to unsold spectrum.) The sum of that column represents the overall opportunity cost for awarding spectrum to each winning bidder. Further, in this CCA the opportunity costs meet all the conditions for base prices laid down in Schedule 5 of the auction rules, so in this auction the base prices are identical to the opportunity costs.

If Vodafone's bids had been excluded then the outcome would have been as follows:

Table 4. Calculation of Vodafone's Vickrey price

BIDDER	A1	A2	C	E	Opportunity cost (£)
Telefonica	0	1	2	0	128,000,000
EE	2	0	6	0	310,500,000
H3G	1	0	2	0	100,000,000
Niche	0	0	3	5	1,000,000
HKT	0	0	0	2	10,250,000
MLL	0	0	0	2	1,011,000
Unsold	1	0	1	0	240,000,000
Totals	**4**	**1**	**14**	**9**	**790,761,000**

Source: Ofcom

Thus Vodafone paid £790,761,000 for two lots of A1, four lots of C and five lots of E.

[28] Strictly speaking the prices in the auction were set based on 'Vickrey nearest' algorithm but in practice the prices paid were equal to Vickrey prices.

If Telefónica's bids had been excluded then the outcome would have been as follows:

Table 5. Derivation of Telefónica's Vickrey price

BIDDER	A1	A2	C	E	Opportunity cost (£)
Vodafone	0	1	4	4	(33,000,000)
EE	2	0	6	0	310,500,000
H3G	1	0	2	0	100,000,000
Niche	0	0	2	5	(52,500,000)
Unsold	1	0	0	0	225,000,000
Totals	**4**	**1**	**14**	**9**	**550,000,000**

Source: Ofcom

Hence Telefónica paid £550m for the A2 lot.

If EE's bids had been excluded then the outcome would have been as follows:

Table 6. Derivation of EE's Vickrey price

BIDDER	A1	A2	C	E	Opportunity cost (£)
Vodafone	2	0	7	9	165,876,000
Telefónica	0	1	2	0	128,000,000
H3G	1	0	2	0	100,000,000
Niche	0	0	3	0	(30,000,000)
Unsold	1	0	0	0	225,000,000
Totals	4	1	14	9	588,876,000

Source: Ofcom

Hence EE paid £588,876,000 for one A1 lot and seven C lots.

If H3G's primary and supplementary round bids had been excluded, the outcome would have been unchanged – H3G's opt-in bid for the same A1 package would have won, and all other bidders would have won the same as they

Annexe 1: Derivation of UK auction prices

did in the real auction. So H3G paid just the reserve price of £225m for one A1 lot.

If Niche's bids had been excluded then the outcome would have been as follows:

Table 7. Derivation of Niche's Vickrey price

BIDDER	A1	A2	C	E	Opportunity cost (£)
Vodafone	2	0	5	9	58,476,000
Telefónica	0	1	2	0	128,000,000
EE	1	0	7	0	0
H3G	1	0	0	0	0
Totals	4	1	14	9	186,476,000

Source: Ofcom

Thus BT/Niche paid £186,476,000 for three C lots and four E lots.

Annexe 2: Decomposition of EE's incremental bids

In order to decompose EE's bids into incremental values, adjusted for any premium we implemented two separate methods:

- Method A assumes that the generic value of spectrum declines linearly and that the value of the premium is constant in absolute terms going from 1 to 2 blocks, as going from 3 to 4 blocks;
- Method B assumes that the generic value of spectrum declines linearly and that the value of the premium is a constant proportion of the total valuation in the overall value from 1 to 2 blocks as from 3 to 4 blocks.

This annex sets out the input data used for the calculations and then explains and illustrates the calculation steps for each method.

Input data

The input data consisted of pairs of bids made by EE in the supplementary round which differed only in the number of A1 blocks bid for.

A summary of the input data is shown below in **Figure 7**.

Figure 7. EE's Relevant paired bids

Number of C blocks bid for	Number of E blocks bid for	Bid with lower number of A1 blocks (£million)	Bid with higher number of A1 blocks (£million)	Differential (£millions)
Pairs of bids from 0 A1 block to 1 A1 block				
0	0	-	230	230
0	9	225	480	255
2	9	306	536	230
2	0	30	260	230
3	0	250	480	230
3	9	501	731	230
4	0	410	640	230
5	0	512	742	230
6	0	624	899	275
7	0	697	1,050	353
Mean				249
Median				230
Pairs of bids from 1 A1 block to 2 A1 block				
0	0	230	650	420
0	9	480	1,090	610
2	0	260	865	605
3	0	480	1,035	556
4	0	640	1,145	505
5	0	742	1,233	491
6	0	899	1,360	461
Mean				521
Median				505
Pairs of bids from 2 A1 block to 4 A1 block				
0	9	1,090	1,564	474
0	0	650	1,177	527
2	0	865	1,445	580
3	0	1,035	1,568	533
4	0	1,145	1,798	653
Mean				553
Median				533

Source: Ofcom bid data

Annexe 2: Decomposition of EE's incremental bids

Method A

Method A estimates the value of blocks of spectrum, excluding the premium, by estimating the gradient by which the incremental value of spectrum (excluding premia) declines with increasing holdings of spectrum.

The first step is to calculate the difference between the incremental value of the first 10 MHz of spectrum bid for (from 0 to 2 A1 blocks) and the incremental value of the second 10 MHz of spectrum bid for (from 2 to 4 A1 blocks). Under the assumption that the premium in both the first and second 10 MHz bid for is the same, this difference solely relates to the declining value of incremental spectrum.

In order to convert this to a gradient per block per block, this difference is divided by the difference in the mid-points of the two increments (15 MHz – 5 MHz = 2 blocks) and the number of blocks in each increment (10 MHz = 2 blocks).

This gradient is then applied to the value for the first 5 MHz block to calculate the value (excluding premia) for the second block (and third and fourth block).

The calculation was carried out for inputs based on median values and median values for each of the incremental value inputs.

The calculations are shown below in **Figure 8**.

Figure 8. Calculations for Method A

		Mean	Median
Differential inputs			
0 -> 1	*A*	249	230
1 -> 2	*B*	521	505
0 -> 2	*C = A + B*	771	735
2 - > 4	*D*	553	533
Calculations			
Difference between first 10 MHz and 2nd 10 MHz	*E = D - C*	- 217	- 202
Number of blocks difference in mid-point	*F*	2	2
Number of blocks in increments	*G*	2	2
Gradient per block per block	*H = E/F/G*	- 54	- 51
Estimated incremental cost exc. Contiguity premia			
0 -> 1	*A*	249	230
1 -> 2	*A + H*	195	179
2 -> 3	*A + 2 * H*	141	129
3 -> 4	*A + 3 * H*	86	78

Source: Frontier Economics analysis of Ofcom bid data

Method B

Method B estimates the value of blocks of spectrum, excluding the premium, by first decomposing the value of the second 10 MHz increment of spectrum bid for (from 2 to 4 A1 blocks) assuming that the value of the third incremental A1 block as a proportion of this overall total is the same as the value of the first incremental A1 block in the value of the first 10 MHz increment of spectrum bid for (from 0 to 2 A1 blocks).

As both the first and third blocks include no premium, the value of the second block excluding the premium can be estimated by interpolation.

The calculations are shown below in **Figure 9**.

Annexe 2: Decomposition of EE's incremental bids

Figure 9. Calculations for Method B

		Mean	Median
Differential inputs			
0 -> 1	*A*	249	230
1 -> 2	*B*	521	505
0 -> 2	*C = A + B*	771	735
2 - > 4	*D*	553	533
Calculations			
First block as percentage of first 10 MHz value	*E = A / C*	32%	31%
Estimated value of 3rd block	*F = D * E*	179	167
Interpolated value of second block (exc. contiguity premium)	*G = (A + F)/2*	214	198

Source: Frontier Economics analysis of Ofcom bid data

FRONTIER ECONOMICS EUROPE
BRUSSELS | COLOGNE | LONDON | MADRID

Frontier Economics Ltd 71 High Holborn London WC1V 6DA
Tel. +44 (0)20 7031 7000 Fax. +44 (0)20 7031 7001 www.frontier-economics.com