Annex A: Further details of the UK's spectrum auctions, 2000–21

The first part of the annex provides more detailed information on the UK's use of auction formats and competition measures. Then, I examine each of the UK's high-stakes spectrum auctions in 2000, 2013, 2018, and 2021 in turn, providing evidence and analysis to support the overview in Section 2.3 and the comparisons of bidding and outcomes in Section 11.1.

A1 Supplementary information on UK auction formats and competition measures

Figure A1.1. Formats used in all UK spectrum auctions, 2000–21

Year	Band	Auction format	Expected (or later) use
2000	2.1 GHz	SMRA	Mobile, 3G
2000	28 GHz (regional licences)	SMRA	Fixed wireless broadband
2003	*3.4 GHz (regional licences)*	*SMRA*	*Fixed wireless broadband; and later, 5G*
2006	DECT guard band: 1781.7–1785 MHz / 1876.7–1880 MHz	Sealed bid, first price, combinatorial	Low power, local networks, up to 12 concurrent licences
2006	412–414 MHz / 422–424 MHz	Sealed bid, first price, combinatorial	Various fixed and mobile services (later, smart meters and emergency services)
2007	1785–1805 MHz in Northern Ireland	Sealed-bid, second price*	All-Ireland broadband^
2007	10 GHz, 28 GHz, 32 GHz, and 40 GHz	CCA	Various services including fixed links
2008	*L Band: 1452–1492 MHz*	*CCA*	*Various services, such as mobile TV or digital radio; and later, mobile capacity (supplementary downlink, SDL)*
2008	758–766 MHz Manchester area	SMRA*	Digital terrestrial television
2008	542–550 MHz Cardiff area	SMRA*	Digital terrestrial television
2013	800 MHz, 2.6 GHz	CCA	Mobile, 4G
2018	2.3 GHz, 3.4–3.6 GHz	SMRA	Mobile, 4G, and 5G
2021	700 MHz, 3.6–3.8 GHz	SMRA	Mobile, 5G

Source: Author from Ofcom auction documents.
Notes: High-stakes auctions are shown in yellow-shaded rows. Others are in alternating blue and white rows, with italics indicating bands that later became mobile spectrum.
* Only a single licence was awarded in these auctions.
^ The 2007 auction for spectrum in Northern Ireland was coordinated with an auction for the same band in the Republic of Ireland.

Figure A1.2. Competition measures in four high-stakes auctions in the UK (MHz amounts given in square brackets)

Auction	Size of spectrum caps (and % of spectrum pool)	Size of reservation
2000, 3G [120]	Bidders were limited to at most one licence in the auction [20 or 30], ensuring five auction winners.	One licence [30] was reserved for a new entrant.
2013, 4G [250]	Two caps on pre-existing holdings plus auction acquisitions: • Total spectrum [210, 37% of 567] • Low frequency, sub-1 GHz spectrum [55, 42% of 130]	Spectrum floor either for the smallest incumbent, H3G • 800 MHz [10]; or • 2.6 GHz paired [40] Or for a new entrant • 800 MHz [30]; or • 800 MHz [20] + 2.6 GHz paired [20]
2018, PSSR [190]	Two caps on pre-existing holdings plus auction acquisitions: • Total spectrum [340, 37% of 917] • Immediately useable spectrum [255, 39% of 647]	None
2021, 5G [200]	One cap on pre-existing holdings plus auction acquisitions: • Total spectrum [416, 37% of 1117]	None

Source: Author from Ofcom auction documents.

Figure A1.1 shows that the UK regulator chose the Simultaneous Multiple Round Ascending Auction (SMRA) format for seven of the 13 auctions between 2000 and 2021, the Combinatorial Clock Auction (CCA) for three, and sealed bids for another three. The high-stakes auctions in 2000, 2013, 2018, and 2021, shown at the top and bottom of Figure A1.1, used either the SMRA or CCA format. The spectrum bands in the two auctions shown in italics in 2003 (using the SMRA format) and 2008 (using a CCA) became mobile spectrum many years later – while at the time of these awards, the bands were not expected to be used by, and were not allocated to, mobile operators, they ultimately became mainstream mobile spectrum because of subsequent technological developments. The UK regulator chose a range of formats for the other lower-stakes auctions in 2000 and 2006–08, including SMRA, CCA, and sealed bids.

Competition measures were especially relevant to the four high-stakes auctions, and Figure A1.2 provides the details. The precise MHz spectrum amounts involved in the caps and reservations are shown in brackets, as well as shares of the pools of mobile spectrum represented by the caps.

A2 Bidding and outcomes in the 2000 auction for 3G spectrum

The UK's first spectrum auction divided opinion, some regarding the high prices and boost to mobile competition from a new entrant as a success, and others bemoaning overpayment for spectrum as a

debacle causing risks of reduced investment and higher consumer prices. 3G technology did not live up to the hype, fuelling the view that operators overpaid for the spectrum. It remains controversial whether there was an adverse effect on investment and prices. Yet there is evidence of an efficient allocation of spectrum to the right winners, and the promotion of mobile competition through a new entrant has been a long-lived benefit.

The auction design was an SMRA format with a simple lot structure of spectrum pre-packaged into five frequency-specific licences with two different amounts of 3G spectrum in the 2.1 GHz band: two larger licences of 30 MHz, one of which was reserved for a new entrant to promote downstream competition; and three smaller licences of 20 MHz. Each participating company was permitted to bid for only one licence in any round. The regulator set the minimum price increments between rounds initially at 5 per cent, and reduced them progressively to 1.5 per cent for the final rounds. There was an open (transparent) information policy because bidders saw the bids and identities of all other bidders after each round.

Bidding and outcomes

In addition to the four incumbent mobile operators (BT, One2One, Orange, and Vodafone), nine other bidders competed to be a new entrant. The bidding took place between 6 March and 27 April 2000, and the auction ended after 150 rounds of bidding with the outcome shown in Figure A2.1. All four incumbents won a licence, paying similar prices per MHz at around £200 million as shown in the second column, and Vodafone paid the highest total price in the third column because it won one of the larger licences (B). The other larger licence (A) was reserved for a new entrant and won by TIW at a much lower price per MHz of £146 million, given that the incumbents were not permitted to bid for this licence. The total prices were, on average, 45 times larger than the reserve prices, leading to revenue of almost £22.5 billion.

All 13 firms remained in the auction for the first 90 rounds, after which seven bidders progressively dropped out. Crescent, 3G UK, Spectrumco, Epsilon, and One.Tel exited in rounds 94 to 101. Worldcom followed in round 121, by which time the lowest priced licence (D) was about £3.3 billion. Telefónica dropped out in round 133 when it would have needed to bid more than £3.7 billion to

Figure A2.1. Winning operators, spectrum amounts, and prices in the 2000 auction

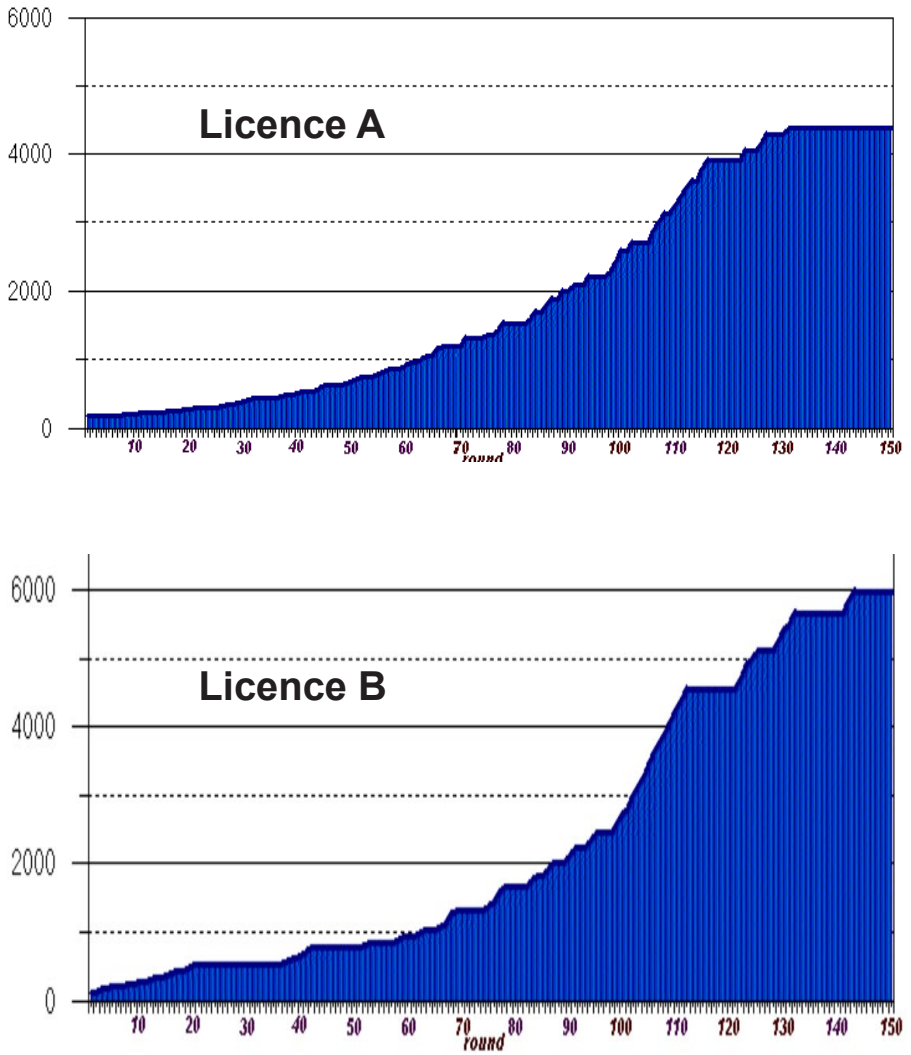
Operator	2.1 GHz spectrum lots[1]	Price per MHz in £ million	Total price in £ million	Reserve price in £ million
Orange	E, 20 MHz	205	4,095	89
BT	C, 20 MHz	202	4,030	89
One2One	D, 20 MHz	200	4,003	89
Vodafone	B, 30 MHz	199	5,964	107
TIW	A, 30 MHz	146	4,385	125
Total or average	120 MHz	187	22,477	500

Source: Author from Ofcom auction documents.
Notes: Auction and reserve prices are rounded to the nearest £ million.
The outcomes are arranged in descending order of price per MHz.

displace a standing high bidder and stay in. This left six bidders competing for the five licences. NTL Mobile, a potential entrant, was the last to drop out to end the auction in round 150 as the highest losing bidder, when prices for all licences exceeded £4 billion.

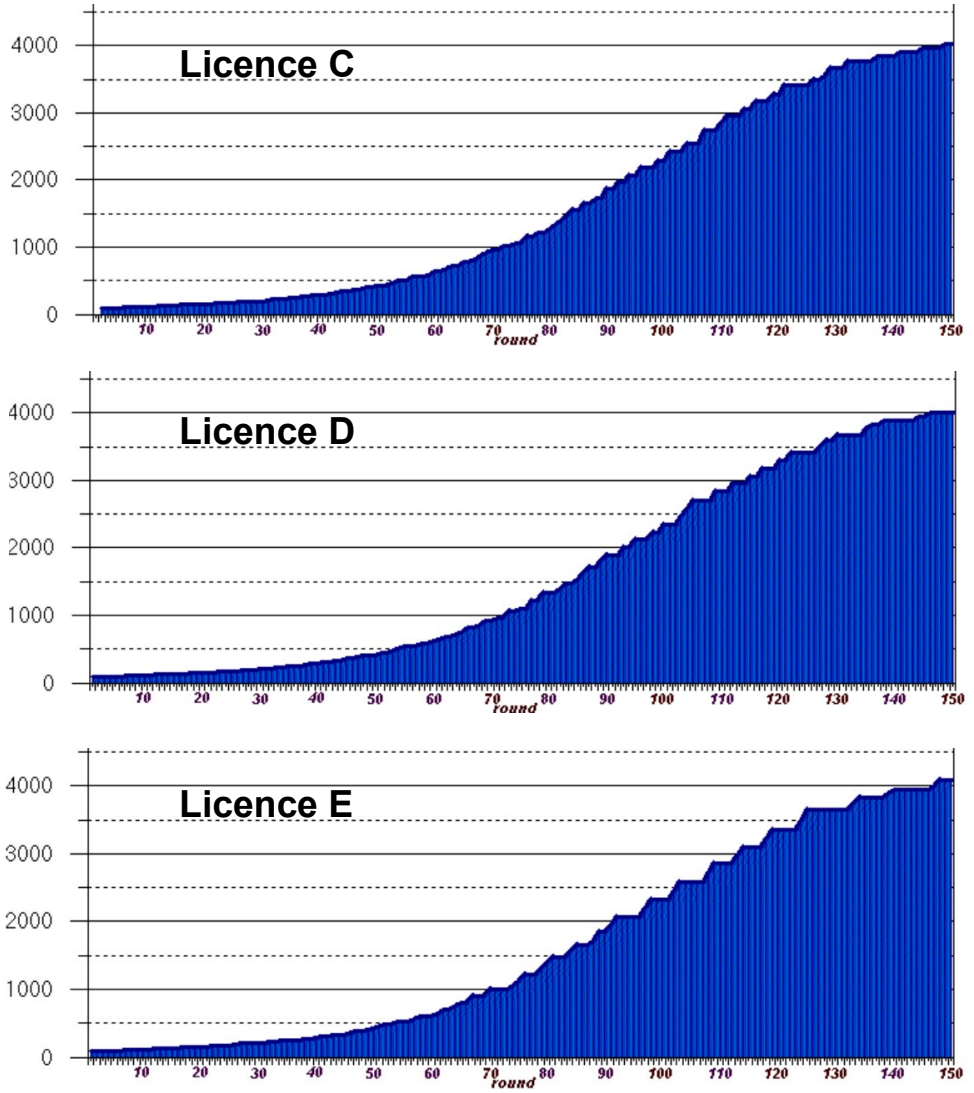
For the two larger licences, A and B, Figure A2.2 sets out the evolution of prices on the vertical axis across the bidding rounds shown on the horizontal axis. The competition between potential new entrants for licence A was resolved in round 132, when NTL Mobile switched away and instead bid for one of the smaller licences. There was no bidding activity in later rounds, and the price remained

Figure A2.2. Prices by round in the 2000 auction for licences A and B (30 MHz each) in £ million



Source: Radiocommunications Agency auction documents.[2]

Figure A2.3. Prices by round in the 2000 auction for licences C, D, and E (20 MHz each) in £ million



Source: Radiocommunications Agency auction documents.

the same at £4,385 million as shown by the flat line from round 132. Vodafone and BT ended up competing for licence B, taking the price close to £6 billion. Vodafone focused solely on bidding for this licence and eventually won it, when BT switched to bidding for a smaller licence in round 144.

Figure A2.3 shows the round prices for C, D, and E, the three smaller licences. The prices for each of these licences increased in a similar way to reach just over £4,000 million by the end of the

auction when NTL Mobile eventually dropped out. The substitutability of these licences contributed to the similar pattern, because non-standing high bidders switched between licences based on their relative prices.

Surprises, mistakes, strategic bidding, and economic efficiency

The official pre-auction estimate of revenue was £1–3 billion, so the surprisingly high prices were up to about 20 times larger.[3] Bidding was very aggressive with prices exceeding the value of the spectrum, at least assessed with the benefit of hindsight, because 3G technology did not lead to as large a step-change in consumer experience as many commentators had expected. Some bidders later expressed regret (see Section 2.3). A range of reasons have been suggested for the extremely high prices:[4]

- The UK was the first of the European 3G auctions, so that bidders were establishing their position in a 'bigger game'.
- BT apparently engaged in price driving against Vodafone for the large licence B.
- There was common value uncertainty about costs and revenue for 3G, so that bidders may have increased their valuations as prices went up.
- The timing of the auction took place at the height of a telecommunications stock market boom.
- Firms were pressured by stock market expectations that failing to win a licence would effectively mean that an operator would have to exit the market. Potentially this led to incumbent operators being willing to bid up to their enterprise value in the mobile market, not just their incremental value for the spectrum actually being sold in the auction.

The last three reasons for the high prices are consistent with the winner's curse, such as the stock market context leading bidders to 'egg each other on' to ever higher prices. In general, experimental evidence has suggested that a winner's curse can apply to experienced business executives. Possible behavioural explanations for them to overbid include bounded rationality, fear of losing, joy of winning, or managerial overconfidence (in this case, about 3G commercial prospects).[5] The final reason about bidding the enterprise value does not seem to account for new entrant valuations – which set the auction prices because NTL Mobile was the highest losing bidder. However, the bid pattern is potentially consistent with an entrant expecting to displace an incumbent should it succeed in winning one of the unreserved licences.

The first operator to offer 3G services to consumers was H3G (which took over the licence acquired by TIW). It linked the timing to its brand name '3', launching on the third day of the third month of the third year of the new millennium, 3/3/2003. There is mixed evidence whether the scale of the auction prices delayed investment in 3G networks, and little evidence of an adverse effect on consumer prices (see Section 7.2). Another possible effect is that the winner's curse and its financial impact on the operators may have led the regulator to apply regulations less stringently, such as not enforcing coverage obligations as rigorously, or being more generous when setting regulated prices (such as wholesale charges for mobile termination).[6]

Some commentators have used detailed analysis of the bids to suggest various types of strategic bidding.[7] However, given the strength of competition, there is little evidence that it adversely affected the efficiency of the outcome in terms of the identity of the winners to deliver the greatest benefits to consumers.

Lessons learned

Operators certainly learned from the experience of the 2000 auction, and avoided the same kinds of aggressive overbidding and inflated prices in later UK auctions. A key lesson for the regulator was that the lot structure of pre-packaged licences simplified the auction, but offered limited flexibility to bidders compared to a more granular product design of breaking the spectrum into smaller lots (see Section 7.5).

The regulator's decision to set-aside licence A for a new entrant was successful in promoting downstream competition. One view is that these benefits to competition came in a trade-off with a loss in auction efficiency, because BT bid more than TIW/H3G for the additional 10 MHz in a larger licence compared to the smaller licence that it won, so that it might have outbid TIW/H3G for the reserved licence A (if that had been allowed).[8] However, these bids by BT for a larger licence may in fact have just been part of its price-driving strategy against Vodafone, instead of reflecting its intrinsic values for the spectrum.[9] Regardless, it is highly likely that any trade-off was still favourable and that overall output efficiency was enhanced, given the important role for competition in the downstream mobile market that has been played by H3G over the subsequent 20 years. For example, it was the first to launch 3G services, and had a track record of offering lower prices than the larger incumbents.[10]

A3 Bidding and outcomes in the 2013 auction for 4G spectrum

In the intervening period between 2000 and 2013, there were nine lower-stakes auctions involving less valuable spectrum (see Figure A1.1). There were consumer benefits from such spectrum being brought into productive use. In addition, bidders and the regulator took on board lessons from the 2000 auction, and were able to use some of the lower-stakes auctions as further learning experiences.

In the media reporting after the high-stakes 2013 auction, the main story was that the revenue of £2.4 billion fell a billion pounds short of pre-auction expectations (see Section 5.1). For the industry the key points of contention were the reservation of spectrum for H3G (the smallest incumbent) and the complexity of the design using the CCA format. A story of surprises and mixed success emerged in the bidding. The evidence is inconclusive whether the unexpected pattern of spectrum allocation was efficient. All the competition measures were binding constraints. While some complications were disproportionate, in my view the most important ones were justified.

How previous lessons were applied

In 2013 for 4G spectrum, operators engaged in far less 'exuberant' bidding than they had in 2000 for 3G spectrum. A contributory factor was less pressure from the capital markets about the existential consequences of failing to win spectrum, and in general firms bidding in the auctions since 2000 have focused much more on the incremental value of the spectrum on offer than on enterprise value.

For the 2013 auction Ofcom recognised the new design challenges, because operators were likely to have within- and cross-band synergies in their valuations, arising from the combination of coverage and capacity spectrum included in the auction – one of the three bands was low-frequency coverage spectrum at 800 MHz, and the other two were capacity spectrum, the 2.6 GHz paired and

2.6 GHz unpaired bands. The prospect of synergies led the regulator to be an early adopter of the latest innovation in spectrum auction formats, the CCA. After experimental testing, it had deployed the CCA format in two lower-stakes auctions taking place before the big award in 2013 – experience in the lower-stakes 10–40 GHz and 1400 MHz auctions in 2007–8 allowed for learning by both the regulator and operators.[11]

In addition, the regulator changed the product design for the spectrum in the auction in two ways. *Smaller* lots, without pre-packaging, provided greater flexibility for bidders over simplicity. The lot structure also included *generic* lots which were not frequency-specific, enabling thicker markets through more bids per lot category. The number of generic lots won by the operators in each category was determined by bidding in the principal stage of the auction, which in the CCA format included both the clock rounds and the supplementary bids round.

The regulator's choice to use generic lots then added a subsequent assignment stage to decide the specific frequencies obtained by the winning firms (see Section 7.4). The assignment stage operated as a separate auction using a sealed-bid, second-price combinatorial format (which was a simpler version of the supplementary bids round in the CCA principal stage). Operators made bids in the assignment stage to express their preferences about the location of frequencies in each band for the spectrum that they had won in the principal stage such as top, middle, or bottom of the band. Firms' preferences can include wanting to be adjacent to a neighbour, perhaps to obtain gains from network sharing (e.g. between Telefónica and Vodafone). Or operators may in some cases prefer to avoid frequencies at the very top or bottom of the band, which can sometimes be adversely affected by usage restrictions caused by the need to coexist with spectrum users in neighbouring bands.

For the competition measures, the regulator again decided to reserve spectrum and impose caps to promote downstream competition. Ofcom developed and applied an articulated competition assessment framework (see Chapter 9) and adopted the innovative approach of spectrum floors for flexible spectrum reservation (see Section 10.1). The competition measures generated heated debate during the policy development phase, and they were finalised in the shadow of threats of judicial review by some firms (although an appeal did not materialise).[12]

Bidding and outcomes

Seven bidders participated in the auction which took place between 18 January and 1 March 2013. The four incumbents were EE (formed by the 2010 merger of One2One and Orange), H3G, Telefónica, and Vodafone. BT had offloaded its mobile operations years before in 2006 to Telefónica, so in 2013 it was a potential re-entrant. Two other smaller bidders failed to win any spectrum, MLL and Hong Kong Telecom.

Bidding in the principal stage of the auction is described in Annex B1. As explained there, the winning packages and prices for the four incumbents and BT were quite different from their packages and prices at the end of the clock rounds, because the winning bids and the highest losing bids were all made in the subsequent supplementary bids round. The first three columns in Figure A3.1 show the outcome of the resulting winning packages of spectrum. The winning bid amounts in the fourth column were far above the reserve prices in the fifth column. The penultimate column sets out the principal stage prices, which were determined under a second-price rule (see Annex B2). Most prices were less than half of the winning bid amounts, as shown in the percentage gaps in the final column.

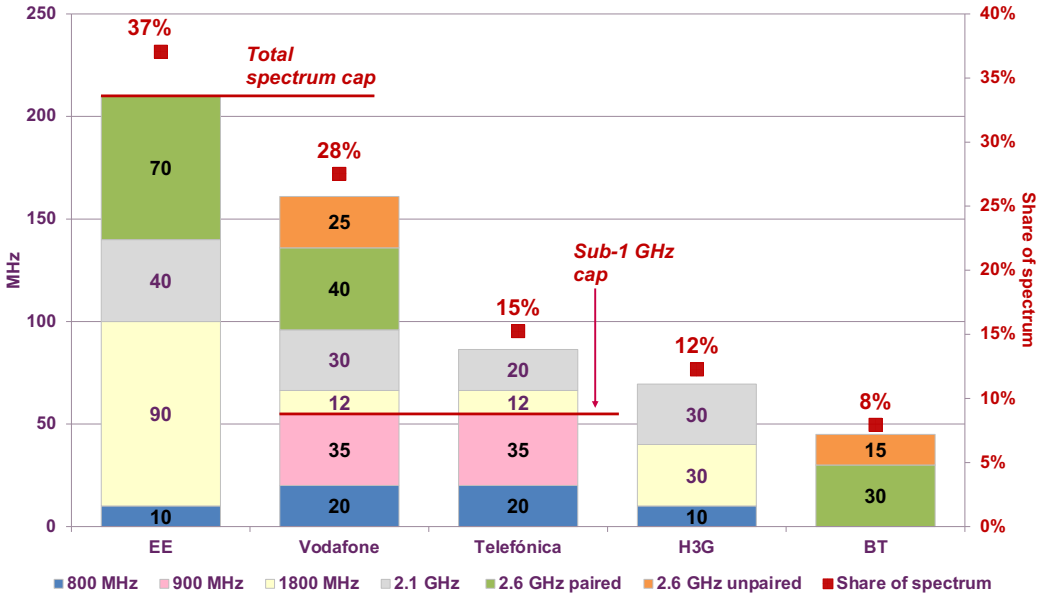
The reserved spectrum was won by H3G (see Section 10.1). The other competition measures of two spectrum caps were also important and turned out to be binding constraints, as shown in

Figure A3.1. Operators' winning packages in 2013 in MHz, and gaps between bid amounts and prices in £ million

Operator	800 MHz	2.6 GHz		Winning bid amount (£m)	Reserve price (£m)	Principal stage price (£m)	Gap (price as % of bid)
		paired	unpaired				
Vodafone	20	40	25	2,075.0	510.5	790.8	38
Telefónica*	20			1,219.0	250	550	45
EE	10	70		1,049.5	330	588.9	56
H3G	10			565.5	225	225	40
BT		30	20	340.4	45.4	186.5	55
Total	60	140	45	5,249.5	1,360.9	2,341.1	45

Source: Author from Ofcom auction documents.
Notes: The outcomes are arranged in descending order of the winning bid amounts.
* Telefónica won the 800 MHz spectrum with the coverage obligation.

Figure A3.2. Operators' spectrum portfolios including amounts won in the 2013 auction showing binding spectrum caps



Source: Author from Ofcom auction documents.

Figure A3.2. For each operator, the stacked bar shows both pre-auction holdings and spectrum acquired in the 2013 auction (800 MHz band in blue, 2.6 GHz paired in green, and 2.6 GHz unpaired in orange). The total cap of 210 MHz limited EE to acquiring 80 MHz of spectrum. The sub-1 GHz cap restricted Telefónica and Vodafone to 20 MHz each in the 800 MHz band. The operators' post-auction

Figure A3.3. Operators' frequency locations in the assignment stage band plans in 2013, with gaps between winning bids and prices set at highest losing bids in £ million

800 MHz band	H3G 2x5 MHz	EE 2x5 MHz	Vodafone 2x10 MHz	Telefónica 2x10 MHz
Winning bids	0	7.0	66.5	n/a
Prices (opportunity cost)	0	0	8.1	n/a

2.6 GHz paired band	Vodafone 2x20 MHz	BT 2x15 MHz	EE 2x35 MHz
Winning bids	11.0	60.9	0
Prices (opportunity cost)	4.0	15.1	0

2.6 GHz unpaired band	Vodafone 25 MHz	BT 20 MHz
Winning bids	4.0	10.1
Prices (opportunity cost)	0	0

Source: Author from Ofcom auction documents.
Note: Bids are rounded to the first decimal point in £ million.

shares of spectrum displayed significant asymmetry in the distribution of holdings. The disparity between EE's 37 per cent share and Telefónica's much smaller 15 per cent share is especially notable, because they provided mobile services to a broadly similar number of subscribers.

The winning bids and the resulting band plans from the assignment stage are shown in Figure A3.3. The assignment stage prices (additional to the principal stage prices in Figure A3.1) are also set out, determined using a second-price rule based on the highest losing bids, reflecting opportunity cost as in the CCA principal stage. In the 800 MHz band, Vodafone bid more than £66 million to express a strong preference to be next to Telefónica, its network sharing partner who won the frequency-specific lot including the coverage obligation at the top of the band (as specified by the regulator before the auction). The highest losing bid for this location was only £8.1 million by EE, so that the second price was a modest proportion (12 per cent) of Vodafone's winning bid. In the 2.6 GHz paired spectrum, BT bid the highest at £60.9 million to obtain the middle of the band. Again, the assignment stage price was substantially lower than the winning bid, reflecting EE's highest losing bid of £15.1 million. In the 2.6 GHz unpaired band, Vodafone and BT differed in their preferences, so the opportunity costs and prices were zero.

Surprises, mistakes, strategic bidding, and economic efficiency

The surprises in the principal stage bidding and the outcomes included:

- The spectrum caps were set as safeguards allowing substantial asymmetry by international standards.[13] But both caps turned out to be binding constraints so that the distribution of spectrum became more asymmetric and less balanced than previously, at the limits permitted by the regulator.

- EE affected this outcome by bidding relatively more aggressively at the margin for 2.6 GHz spectrum than for 800 MHz. It won as much as one-half of the entire 2.6 GHz paired band. However, it only acquired 10 MHz in the 800 MHz band even though it had no pre-existing low-frequency spectrum in its portfolio.
- BT outbid incumbent mobile operators to win a material amount of spectrum in the 2.6 GHz paired and unpaired bands, despite making some puzzling bids. For example, in a few cases BT placed lower bid amounts for larger than for smaller packages, expressing *negative* incremental bid values.[14]
- Auction bids led to the choice of spectrum floor being the more valuable 800 MHz spectrum than the 2.6 GHz paired (see Section 10.1).

There was limited price and package discovery in the clock stage (see Annex B1). The absence of tighter activity rules in the auction design contributed to this undesirable situation in 2013, as well as the regulator's choice of eligibility points which effectively only permitted switching in one direction between bands (see Annex B3).

Operators and commentators have made various allegations about strategic bidding.[15] Some bids in the clock stage were very likely to have been strategic, such as Telefónica's bids for a low-power, concurrent 2.6 GHz paired licence, as in its final clock round package. It was probably parking eligibility at low prices to provide more flexibility for later clock rounds and for its supplementary bids in the next stage. Some other bids were plausibly strategic, such as those leading to excess supply in the two highest-value bands at the end of the clock stage.[16] However, it is far less clear that significant strategic bidding was involved in the supplementary bids which determined the final outcomes. Ofcom has considered and provided detailed reasoning to reject some allegations about price driving and strategic investment in EE's bids.[17]

Budget constraints affecting two bidders could have influenced the outcome, because companies find these harder to manage in a CCA due to the second-price rule (see Section 8.2).[18] On the other hand, package bidding in the CCA format allowed bidders with synergistic values to express them, such as EE (see Annex B1). Overall, therefore, the evidence is not conclusive on whether the spectrum allocation achieved in the principal stage in 2013 was economically efficient.

Lessons learned

The regulator learned from the lack of price and package discovery in the 2013 auction clock stage and the issues for bidders in managing budget constraints. Ofcom has not held a CCA since 2013 but it has put forward CCA designs on two occasions (firstly, put forward as an alternative to its preferred SMRA design for the 2018 auction, and then proposed for the 2021 auction if coverage obligations had been included).[19] In both cases, Ofcom suggested a CCA design including tighter activity rules to improve price and package discovery, which in turn could assist budget-constrained bidders through greater predictability of the outcome.

There is a good case that the *complexity* of the CCA format arising from package bidding was justified for the 2013 auction because of the cross-band synergies. But where these synergies are less important, a simpler format is preferable. An additional complication of spectrum floors provided justified flexibility because the evidence is at least consistent with a more economically efficient choice of reserved spectrum than under set-aside (see Section 10.1). However, a further complication was less successful. The design for the 2013 auction included competition for part of the 2.6 GHz

paired spectrum between individual standard-power and multiple concurrent low-power licences, only one of which could win. The basic concept was to use auction bids for a licensing policy choice which was not self-evident before the auction as between exclusive and shared use of this spectrum. But there was little evidence of intrinsic-value bids for the low-power licences, suggesting (with hindsight) that it would have been better for the regulator to take the policy decision instead of leaving it for auction bids to decide. The bidding did not directly affect the outcome, but it was another contributor to the lack of price and package discovery in the clock phase.[20] A lesson for the regulator from this mixed experience in 2013 auction was to use the 'heavy machinery' of the CCA only when it is really needed.

The experience that spectrum reservation and both caps were binding constraints reiterated the importance of competition measures in the auction. A final lesson is that, whatever the merits of the second-price rule in the principal stage, it worked well for the simpler assignment stage in incentivising straightforward expression of operators' preferences.

A4 Bidding and outcomes in the 2018 auction for PSSR spectrum

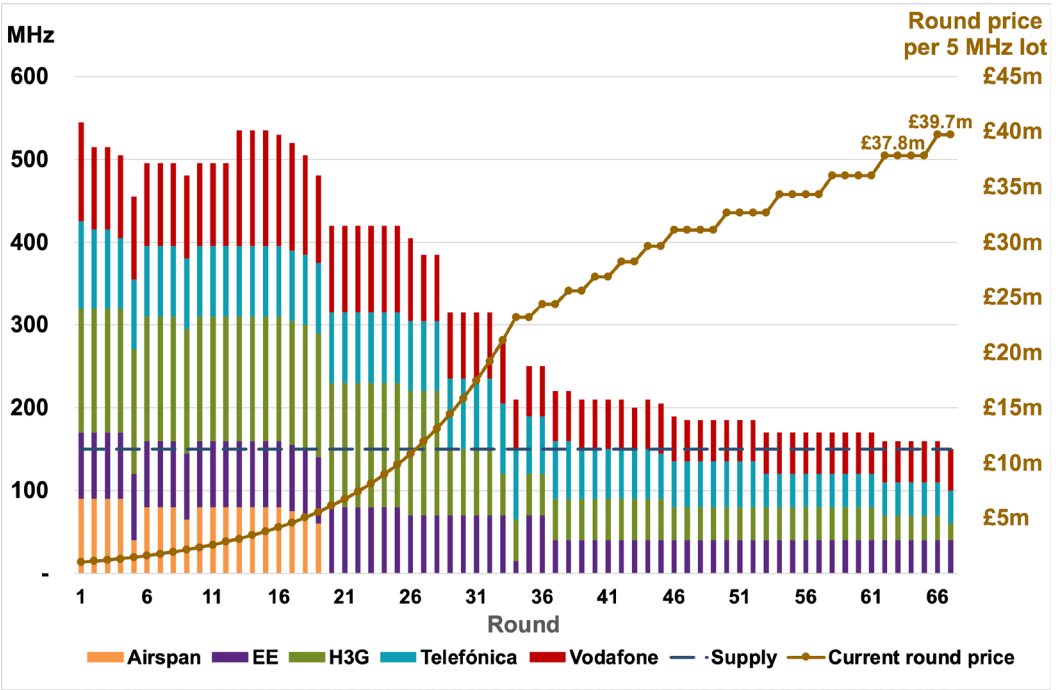
The next auction in 2018 included bands from Public Sector Spectrum Release (PSSR) by the Ministry of Defence. One band on offer (2.3 GHz spectrum) was immediately useable for 4G, and the other (3.4–3.6 GHz) was prime spectrum for early 5G deployments which were expected to start a year or so after the auction. The incumbent operators were especially concerned to win spectrum for 5G, which they all managed to achieve. Contentious issues were confined to the policy development phase, notably the threat of litigation over spectrum caps. In the event, both bidders and the regulator were happy with the auction itself.

How previous lessons were applied

The circumstances for the 2018 auction were simpler than in 2013. With little evidence of cross-band synergies, Ofcom preferred the SMRA format, using a version with generic lots and prices in each round set by the regulator (sometimes called the SMRA-clock hybrid design). A further rationale was the pay-as-bid rule which made bid strategies easier for budget-constrained operators.

Ofcom introduced a few complications through the detailed rules to provide more flexibility to bidders. For instance, if an operator was a partial standing high bidder after any round, it was permitted in the next round to withdraw its bid. The reason was to mitigate substitution risk, although penalties also applied if the spectrum was left unsold as a consequence (see Section 8.2). In fact, no bid withdrawals were made in the auction. In addition, before the start of bidding the regulator gave operators an option to nominate a minimum requirement up to 20 MHz in the 3.4–3.6 GHz band. If a firm did this and yet was left as a partial standing high bidder with less its nominated amount in standing high bids at the end of the auction, then it would not have been required to buy any such smaller spectrum amount. Ofcom introduced this detailed rule to mitigate aggregation risk arising from within-band synergies up to 20 MHz by introducing an element of package bidding into the SMRA format. If the minimum requirement option was taken up (which remains confidential information), the provision did not need to be activated because there was no partial standing high bidder at the end of the auction.

Figure A4.1. Operators' bids and prices in the 3.4–3.6 GHz (5G) band in 2018 by round and bidder



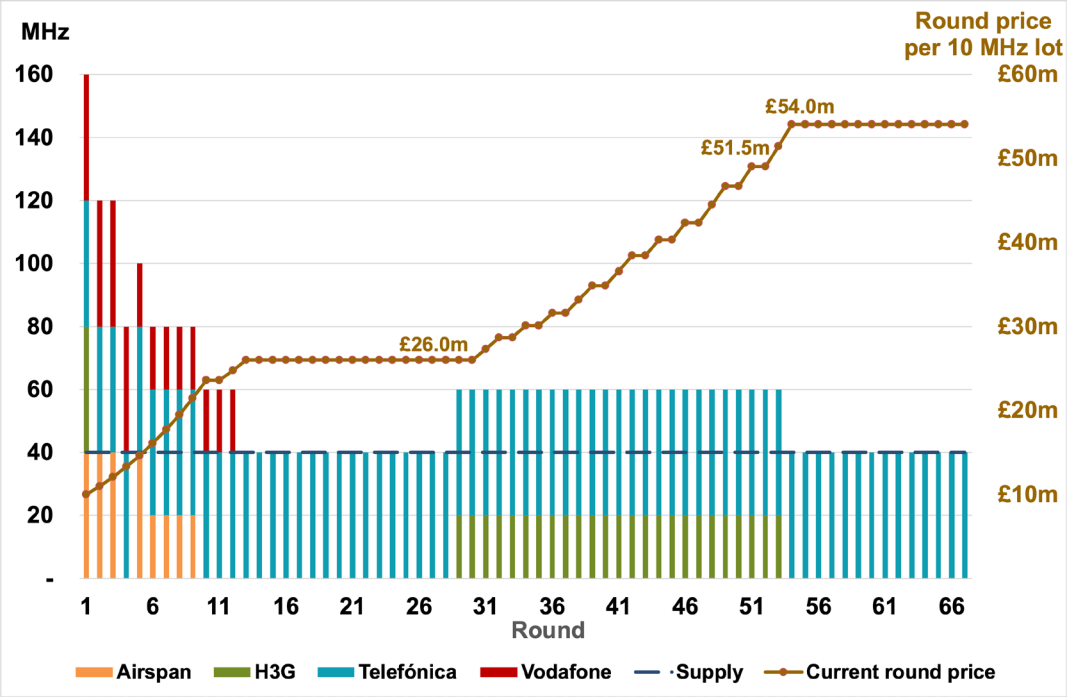
Source: Author from Ofcom auction documents.
Note: Waivers were used by Airspan in round 4, EE in round 34, and Vodafone in round 43.

The two spectrum caps on immediately useable and total spectrum reflected the regulator's continued proactive use of competition measures, which it justified in a detailed, evidence-based assessment. The decision to impose caps was appealed to the courts, delaying the auction by four months. However, Ofcom's decision was upheld (see Section 5.4).

Bidding and outcomes

The four incumbent mobile operators bid in 2018, plus a potential new entrant, Airspan (which had acquired some spectrum in a recent auction in Ireland). The principal stage lasted for 67 rounds of bidding between 20 March and 4 April 2018. The bids and prices in each round for the 5G spectrum in the 3.4–3.6 GHz band are shown in Figure A4.1. All five companies started by bidding for large blocks of 80 MHz or more in the early rounds, indicated by the different colours for the bidders in the stacked bar for each round. In the first few rounds aggregate demand of more than 500 MHz greatly exceeded the available supply of 150 MHz. Prices continued to increase through the rounds due to excess demand and operators reduced the amount of spectrum they were bidding for. Airspan dropped out of the band in round 20, leaving the four incumbents to compete. They all progressively

Figure A4.2. Operators' bids and prices in the 2.3 GHz (4G) band in 2018 by round and bidder



Source: Author from Ofcom auction documents.
Note: A waiver was used by Airspan in round 4.

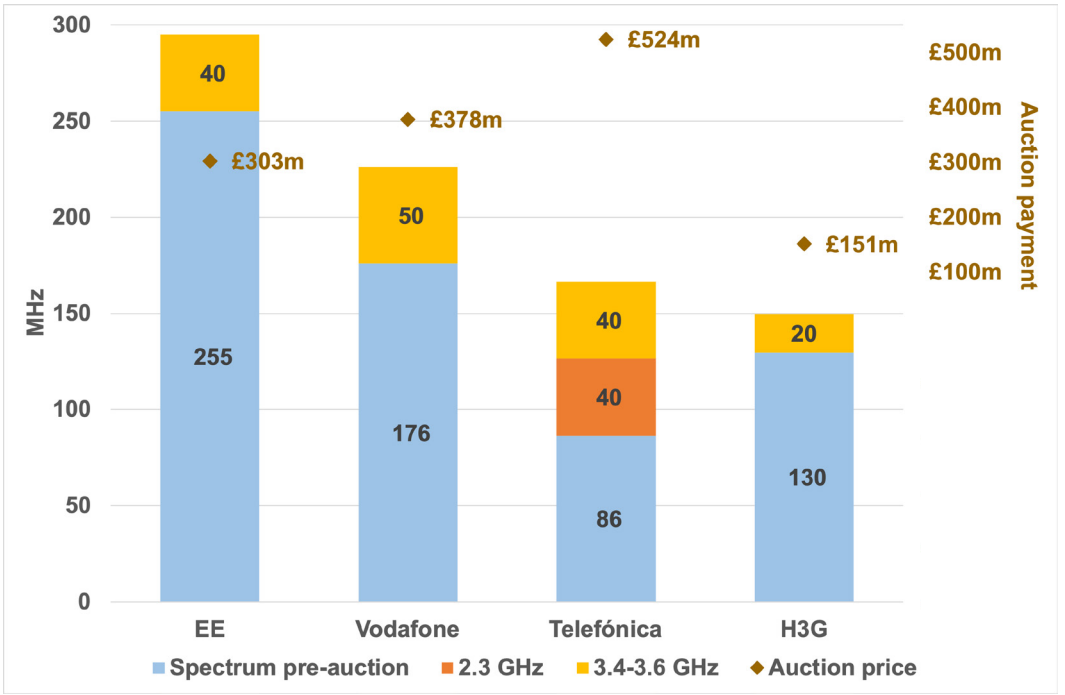
reduced their demand until round 67 when H3G dropped its bid to 20 MHz at a price of £39.7 million per 5 MHz. This cleared the market, bringing aggregate demand down to match supply.

For the 4G spectrum in the 2.3 GHz band, Figure A4.2 shows that Telefónica bid for all of the available 40 MHz in every round. EE was not permitted to bid for this band due to the cap on immediately useable spectrum. Other operators made bids in the early rounds and then dropped out by round 13. There were no new bids until round 29, when H3G switched some of its demand from 3.4–3.6 GHz back into this band. (There was the opportunity for operators to substitute between bands because it was a simultaneous auction.) H3G continued to bid as prices rose until it dropped out in round 54, and there were no new bids after that. The consequence of H3G re-entering the band in round 29 before dropping out again was that the price paid by Telefónica approximately doubled, from £26 million per 10 MHz lot to £51.5 million. (The higher price of £54 million in Figure A4.2 was faced by only H3G, which caused it to drop out.)

The principal stage outcomes and their impact on each operator's spectrum holdings are shown in Figure A4.3. Airspan was outbid by the incumbent mobile operators. Telefónica won spectrum in both bands, and the other three incumbents won 5G spectrum in the 3.4–3.6 GHz band. The cap on total spectrum was set at 340 MHz, so that it was not close to being a binding constraint in this auction. Figure A4.3 also sets out the payments by the winning bidders, yielding revenue of £1.36 billion.

There was no assignment stage bidding for the 2.3 GHz band, because Telefónica won all that spectrum. In the 3.4–3.6 GHz band, the assignment stage bids and outcome are shown in Figure A4.4,

Figure A4.3. How the outcomes of the 2018 auction changed operators' spectrum holdings



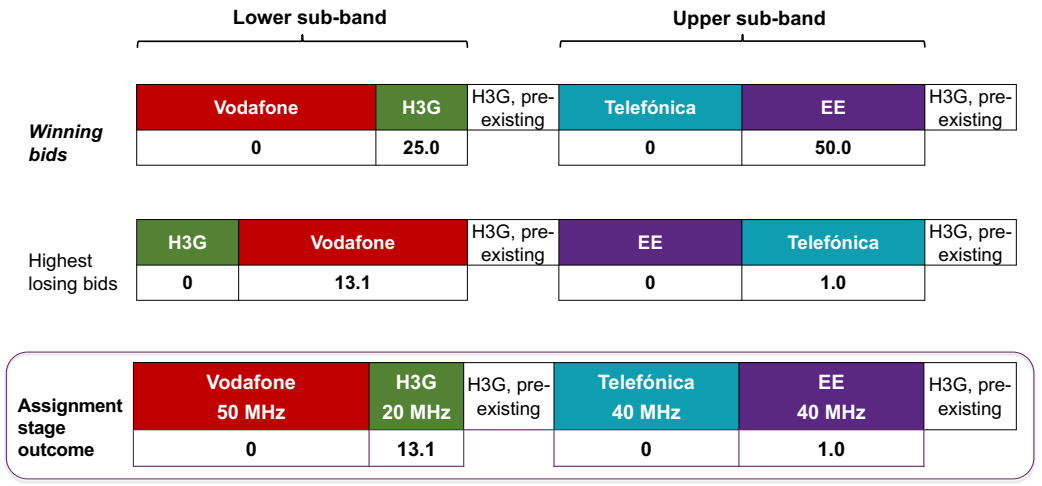
Source: Author from Ofcom auction documents.

providing a simple illustration of the second-price rule. Each operator had two assignment options for either the top or bottom of their respective sub-bands (fitting around the pre-existing spectrum held by H3G which was not included in the auction). The winning bids are set out in the first row in Figure A4.4, such as £25 million by H3G in the lower sub-band for the top location adjacent to its pre-existing holding. The assignment stage price of £13.1 million shown in the last row was set by the Vodafone's highest losing bid in the middle row. In the upper sub-band, EE made the highest bid for the top location at £50 million and paid a drastically lower price of just £1 million which was set by Telefónica's losing bid.

Surprises, mistakes, strategic bidding, and economic efficiency

Instead of the possible outcome of one or two firms winning very large 5G spectrum blocks, which some commentators expected, the competitive bidding in the 3.4–3.6 GHz band led to all four incumbent operators obtaining a significant block of at least 40 MHz, allowing them all to deploy 5G services the following year. This looked like an efficient allocation supporting 5G competition in the downstream market. The allocation of the 4G spectrum, 2.3 GHz, was also desirable – before the auction Telefónica had held the least spectrum, in part because of its limited acquisitions in the 2013 auction. But its large customer base of 33 per cent of network subscribers translated into strong demand for the band to relieve the risk of capacity constraints.

Figure A4.4. Operators' frequency locations in the assignment stage band plan for 3.4-3.6 GHz spectrum in 2018, with gaps between winning bids and prices set at highest losing bids in £ million



Source: Author from Ofcom auction documents.
Note: Bids are rounded to the first decimal point in £ million.

Was the doubling of the 2.3 GHz price after H3G re-entered the band in round 29 a result of *straightforward* intrinsic-value bidding or *strategic* price driving? The available evidence is consistent with both possibilities. H3G could have had intrinsic value for more 4G spectrum, or it could have taken the view that it was safe to engage in price driving due to the known strength of Telefónica's demand (see Section 8.3).

The assignment stage worked well again. It was a surprise at the time that EE bid as much as £50 million for the top of the 3.4–3.6 GHz band, amounting to 17 per cent of its principal stage price. However, it had a very good reason, namely to be closer to the 3.6–3.8 GHz spectrum which it knew would be included in the next auction (see Section 11.3 on defragmentation of the wider 3.4–3.8 GHz band).

Lessons learned

The 2018 auction was successful, in both the principal and assignment stages, and all parties were happy with the outcome and the bidding process. Operators were able to express their bid preferences and compete for spectrum. All four incumbents won spectrum at prices far higher than the potential entrant, Airspan, was willing to pay. The outcome, supporting strong competition in both 4G and 5G services, was good for economic efficiency, competition, and mobile consumers.

The competition measures of two spectrum caps also did the jobs they were supposed to. The cap on immediately useable spectrum prevented the risk of possible strategic investment by EE in the 2.3 GHz band. The total spectrum cap was a safeguard provision, and was not a binding constraint in this auction. In addition, the pre-auction litigation solidified the regulator's analytical approach to deciding competition measures.

A5 Bidding and outcomes in the 2021 auction for 5G spectrum

After delays due to the Covid-19 pandemic, the 2021 auction awarded two high-value bands: more prime 5G spectrum at 3.6–3.8 GHz, and low-frequency coverage spectrum at 700 MHz. In addition, there was a low-value band, also at 700 MHz, which was expected to be used for supplementary downlink (SDL). In the policy development phase, coverage obligations had been especially controversial. However, they were dropped as unnecessary when the government reached a coverage agreement with the operators, substantially simplifying the auction (see Section 5.3). Another key issue for operators was fragmentation in the wider 3.4–3.8 GHz band between separate, non-contiguous blocks of 5G spectrum acquired in two auctions in 2018 and 2021.

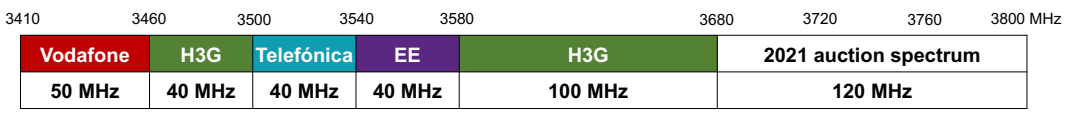
How previous lessons were applied

Ofcom concluded that circumstances were sufficiently similar to use the same basic principal stage auction design as in 2018 (see Section 5.1). In fact, a simpler version of that SMRA design was achieved by removing the minimum requirement option and bid withdrawals, judged as less important in 2021 because all mobile operators already had a significant block of 5G spectrum and so aggregation risks were smaller. Substitution risk was also reduced given the lack of substitutability between the bands in the 2021 auction. So the regulator decided that the trade-off between simplicity and flexibility favoured paring back the auction design.

There was a standard assignment stage design for the 700 MHz paired and SDL bands. However, concerns about fragmentation of the wider 3.4–3.8 GHz band complicated the assignment stage for the 3.6–3.8 GHz spectrum. Figure A5.1 shows the position before the 2021 auction. Any acquisitions in the auction by EE, Telefónica, or Vodafone in 3.6–3.8 GHz spectrum at the top of the wider band would have necessarily been non-contiguous with their existing holdings in the rest of the wider band.

However, there was disagreement about the size of efficiency losses from non-contiguous blocks, and so the importance of defragmentation and how to facilitate it were contentious. The regulator viewed the efficiency losses as undesirable but modest. It decided to rely on post-auction spectrum trading between operators for defragmentation, introducing a novel provision for the assignment stage to set up this process. After principal stage winners made their assignment stage bids, they were not processed immediately. Instead there was a four-week period for the operators to negotiate to see if they could agree the 3.6–3.8 GHz band plan for the spectrum auctioned in 2021. In and around these discussions, they could also negotiate post-auction trades to defragment the wider 3.4–3.8 GHz band, joining up their separate blocks. The negotiation period was split into two phases. In the first phase of three weeks, operators could reach unanimous agreement on the band plan. In the last week, a coalition comprising only a subset of the principal stage winners could also reach a partial agreement.[21]

Figure A5.1. Operators' spectrum holdings in the wider 3.4–3.8 GHz band before the 2021 auction



Source: Author.

Band plans in some other countries have been agreed unanimously between operators, but the *partial* agreement process was new to this auction. The regulator decided that the operators in the partial agreement coalition, which in practice turned out to be Telefónica and Vodafone, would only be agreeing to receive frequencies next to each other. The remaining operator(s), in practice EE, would obtain their preferred location(s) as indicated in their assignment stage bids. The regulator also departed from its usual post-auction full transparency, deciding not to publish assignment stage bids in this band in order to avoid publication adversely affecting post-auction trades.

The competition measure imposed was a total spectrum cap as a safeguard, which was not expected to be a binding constraint. This cap was far less controversial than in previous auctions, because operators' spectrum portfolios were larger and spectrum shares more symmetric (see Figure 9.5). The regulator's rejection of sub-caps on either low-frequency or 5G capacity spectrum was more contentious. The potential concern in the 700 MHz band was that Telefónica and Vodafone (with already relatively large shares of low-frequency coverage spectrum) could make strategic investments to shut out EE and H3G (with small shares). For 3.4–3.8 GHz spectrum, the issue was that H3G could use strategic investment or price driving against the other three operators, given its already large holdings in the wider band, well-suited to provide 5G services. The regulator concluded that such risks were not large enough to warrant imposition of sub-caps, a view later vindicated by the auction outcome.

Bidding and outcomes

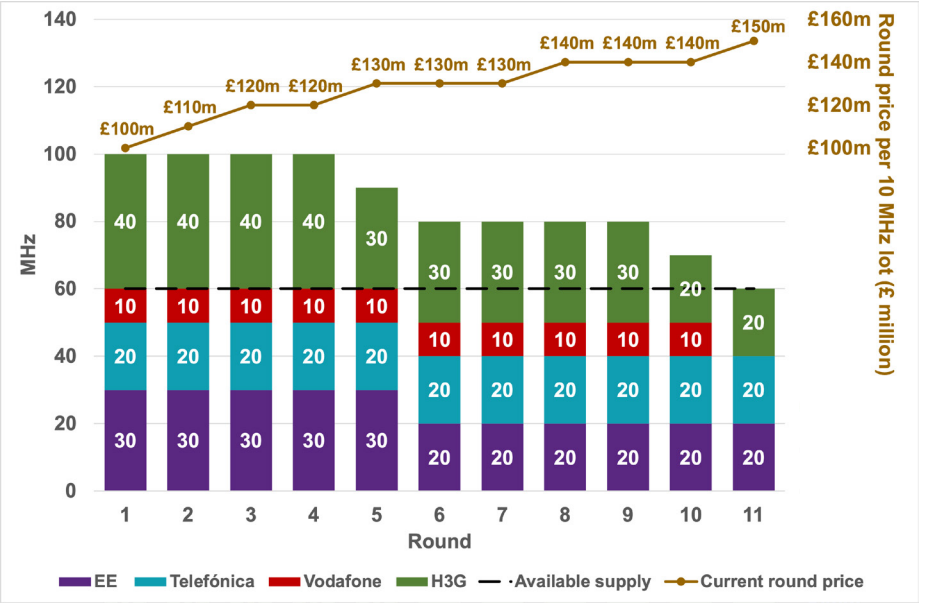
The 2021 auction was the first incumbents-only award, without any potential new entrant. (BT was not a bidder because it had taken over EE in 2016). Potential entrants had contributed to competition in previous auctions, whether going on to acquire spectrum (TIW/H3G in 2000, and BT in 2013) or dropping out before the end. Their absence increased the likelihood of strategic bidding by the incumbents to reduce auction prices.

There were only 11 rounds of bidding in the principal stage on three days between 12 and 16 March 2021, shown in Figure A5.2 for the low-frequency 700 MHz paired spectrum. All four operators made bids for different amounts of spectrum in the first round at the reserve price of £100 million per 10 MHz. As prices went up because of the excess demand, three of the bidders reduced their demand. Telefónica bid for a third of the available spectrum (20 MHz) from the outset, and was later joined by EE in round 6, and then by H3G in round 10. Vodafone bid for 10 MHz until it dropped out in round 11 when the price increased above £140 million. This cleared the market with a three-way equal split. In the other 700 MHz band for SDL, only a single bid was made at the reserve price in the first round by EE and no further bids (and so with a single winner, no assignment stage was needed).

Turning to the 3.6–3.8 GHz spectrum there were just four rounds of active bidding, as set out in Figure A5.3. H3G made no bids in the band (so the other operators' pre-auction concerns about strategic investment or price driving did not materialise). In the first round the other three operators bid for different sizes of large blocks at the reserve price of £20 million per 5 MHz. Then they reduced demand to 40 MHz each, starting with Telefónica in round 2, followed by Vodafone in round 3, and EE in round 4.[22] Thereafter no-one made new bids in the other seven rounds, maintaining the equal market division at close to the reserve price.

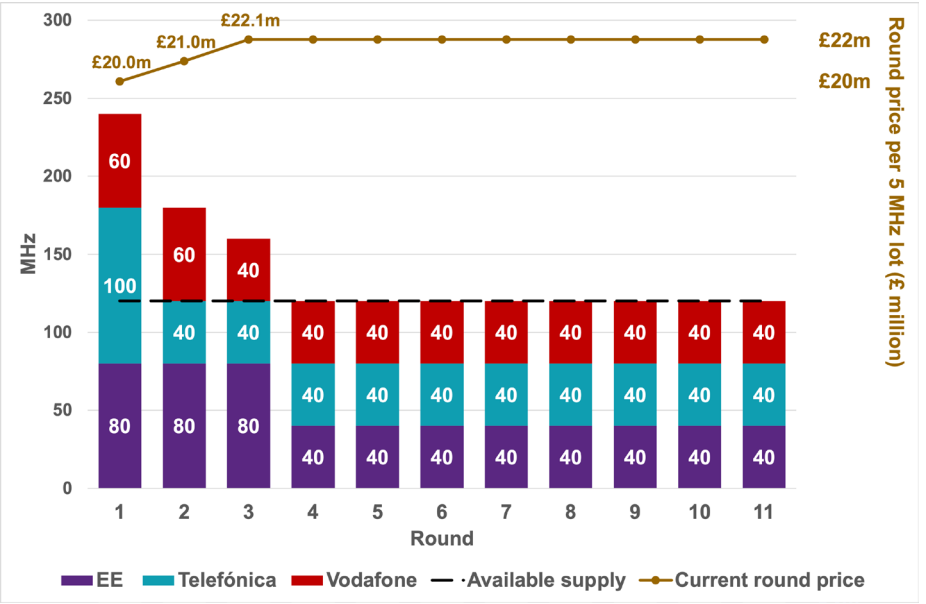
The impact of the principal stage outcome on operator's holdings is shown in Figure A5.4. EE won spectrum in all three bands in the auction, Telefónica in both high-value bands, H3G just in 700 MHz paired, and Vodafone in 3.6–3.8 GHz. As in 2018, all the operators ended with their holdings well short of the total cap level, now set at 416 MHz. Abstracting from the 700 MHz SDL low-value band,

Figure A5.2. Operators' bids and prices in the 700 MHz paired band in 2021 by round and bidder



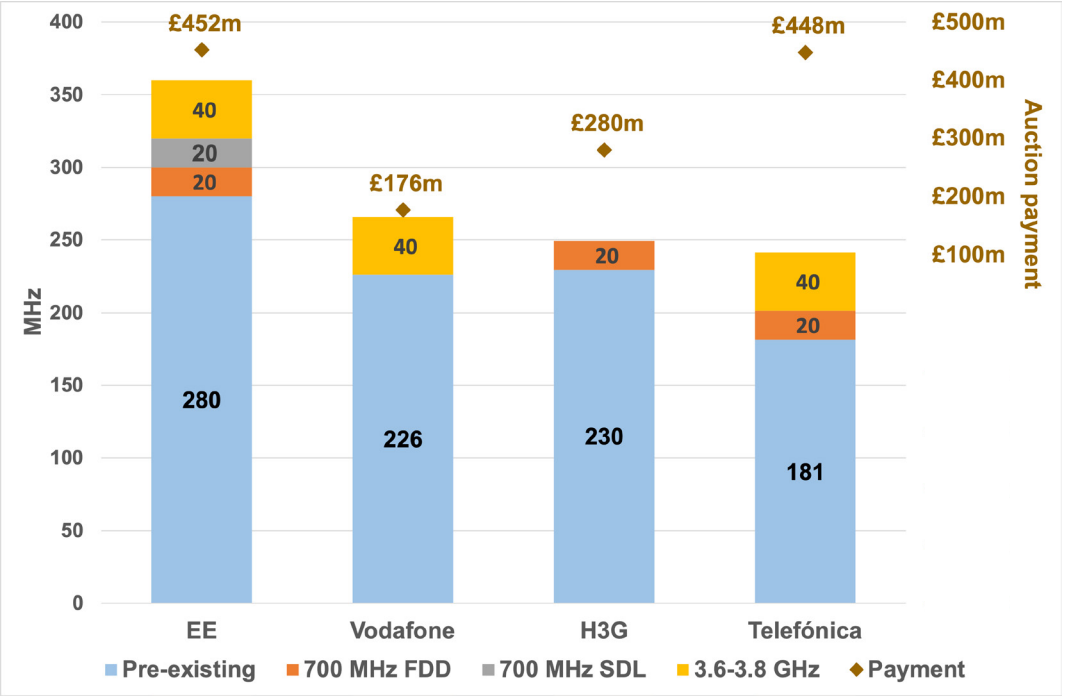
Source: Author from Ofcom auction documents.

Figure A5.3. Operators' bids and prices in the 3.6–3.8 GHz band in 2021 by round and bidder



Source: Author from Ofcom auction documents.

Figure A5.4. How the outcomes of the 2021 auction changed operators' spectrum holdings



Source: Author from Ofcom auction documents.

which operators other than EE did not want even at the very low reserve price, the extent of spectrum asymmetry was maintained or slightly reduced by this outcome. Figure A5.4 also shows the principal stage payments by each operator, generating revenue of £1.36 billion.

Turning to the assignment stage, the key bids and the outcome for the 700 MHz paired band are given in Figure A5.5. EE won the location at the top of the band, because it made a very large bid of £200 million, as shown in the highest-value set of bids in the first row. EE also bid as much as £164.5 million for the middle of the band, and this bid formed part of the next highest-value combination in the second row. In the outcome set out in the final row, EE paid the price of £23 million set by the highest losing bidder for the top location, Telefónica. The assignment stage prices were zero for H3G's and EE's locations.[23]

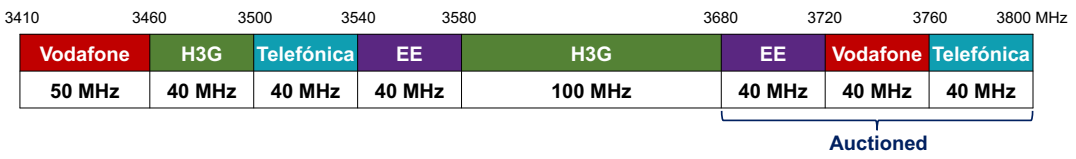
For the 3.6–3.8 GHz band the assignment stage bids were not published, but the outcome is shown on the right-hand part of Figure A5.6. Telefónica and Vodafone reached a partial agreement after a four-week negotiation period. They therefore had to be located next to each other (in the order set out in their agreement). EE, which was outside the partial agreement coalition, obtained the bottom of the band, as close as feasible to its existing block at the top of the 3.4–3.6 GHz band from the previous auction in 2018. The outcome in Figure A5.6 also shows the frequency pattern of fragmented holdings in the wider 3.4–3.8 GHz band locations at the end of the auction. However, the negotiation phase in the assignment stage also facilitated post-auction spectrum swaps between Telefónica and Vodafone which led to significant defragmentation – see Section 11.3.

Figure A5.5. Operators' frequency locations in the assignment stage band plan for 700 MHz paired spectrum in 2021, with gaps between winning bids and prices set at opportunity cost in £ million

Position in the band	Bottom	Middle	Top
Winning bids	Telefónica 0	H3G 1.0	EE 200.0
Highest losing bids	H3G 0	EE 164.5	Telefónica 23.0
Assignment stage outcome	Telefónica 2x10 MHz 0	H3G 2x10 MHz 0	EE 2x10 MHz 23.0

Source: Author from Ofcom auction documents.
Note: Bids are rounded to the first decimal point in £ million.

Figure A5.6. Assignment stage outcome for 3.6–3.8 GHz spectrum in the 2021 auction and fragmented holdings in the wider 3.4–3.8 GHz band



Source: Author from Ofcom auction documents.

Surprises, mistakes, strategic bidding, and economic efficiency

In the 11 rounds of bidding for the 700 MHz paired band, the strength of competition was unclear. There was no strong reason to see the outcome as an economically inefficient allocation, and the bidding could have reflected straightforward bids of intrinsic value. Alternatively, operators could have adopted an element of strategic demand reduction or market division to win spectrum at a lower price.[24] The 700 MHz price of £140 million per 10 MHz was relatively low by international standards (and firmly towards the lower end of a wide range in relative-value benchmarks from £95–507 million).[25] However, this evidence was far from conclusive, given the large variation in prices between countries and auctions (see Section 7.3).

The 2021 auction was not at all competitive in the other two bands. There was strong evidence that bidders engaged in coordinated market division (tacit collusion) in the 3.6–3.8 GHz band. The bid

pattern showed three operators taking it in turns to reduce their demand to the focal point of 40 MHz each to win spectrum at low prices — Telefónica in round 2 inviting Vodafone and EE to drop their demand, which they then did in the next two rounds.[26] The equal allocation of spectrum was a crystal–clear focal point, because it was both a desirable amount for each firm and would allow post-auction swaps to achieve defragmentation. The price paid of £21 million per 5 MHz was only one price increment above the reserve price. It was 45 per cent lower than the £37.8 million for the very similar 3.4–3.6 GHz spectrum in the 2018 auction.[27] Limited competition in the auction therefore depressed prices and revenue.

However, the outcome still probably involved an efficient allocation, allowing each operator to have a holding of at least 80 MHz in the wider 3.4–3.8 GHz band, an amount widely recognised as desirable because of technical efficiencies from using 5G technology.[28] In addition, the outcome in both high-value bands seemed favourable for promoting downstream competition. Operators with less low-frequency or 5G spectrum acquired desirable amounts, so that their respective portfolios enabled strong competition for consumers in terms of both coverage and capacity (although how far that occurred also depended on many other considerations).

The assignment stage of the 700 MHz paired band involved surprisingly high bids from EE (see Figure A5.5). Operators' valuations for specific frequency locations in the band are typically a modest proportion of the prices which they pay for the amount of spectrum in the prior principal stage, 10 per cent or less. However, EE's winning assignment stage bid (£200 million) was more than 70 per cent of its principal stage price for the spectrum (£280 million). Other operators' assignment bids were in line with typical expectations, as reflected in EE's opportunity-cost price (set by Telefónica's losing bid which amounted to only 8 per cent of the principal stage price). The novel feature of partial agreement in the assignment stage for 3.6–3.8 GHz spectrum was put into operation and facilitated post-auction spectrum trades.

Lessons learned

Even though the 2018 and 2021 auctions used the *same* essential design, the bidding experiences were extremely *different*, as highlighted by the comparison between 67 rounds of competitive bidding for 3.4–3.6 GHz in 2018 and just 4 rounds of market division (tacit collusion) for 3.6–3.8 GHz in 2021. It was obviously not only the auction design that affected the bidding, and the circumstances were far less conducive to competition in the 2021 auction. Focusing on economic efficiency, the success of the 2021 auction emphasised that competition in the auction is only a means to an end. Weak rivalry in the auction certainly raised risks of undesirable results and reduced the revenue received by the Treasury. But a case can be made that the short, tacitly collusive bidding process nevertheless achieved a desirable outcome benefitting consumers and retail competition in 5G services.

Could auction revenue have been increased by a different design? The regulator could have set a higher reserve price for the 3.6–3.8 GHz band, given the quality and relevance of the available benchmark of the 3.4–3.6 GHz price from the previous auction in 2018. Yet there was much more uncertainty about the market value of the other bands – the low reserve price for 700 MHz SDL proved to be justified, and it was not clear that the reserve price for 700 MHz paired spectrum affected the outcome. A further possibility would have been to use the alternative CCA format which is generally much less vulnerable to market division than SMRAs (see Section 8.3), and could perhaps have made more of the limited bidding competition that existed. However, the same unusually clear focal point

would still have existed to assist a three-way market division by EE, Telefónica, and Vodafone.[29] In addition, the CCA's heavy machinery could have had downsides, and the UK regulator's duties excluded revenue-raising as an auction objective in any case.

Notes

[1] Licences A, C, D, and E also each included 5 MHz of unpaired spectrum in the 1900 MHz band, although subsequently this spectrum has been little used.

[2] Source: Radiocommunications Agency, part of the Department for Trade and Industry, and one of the legacy regulators before the creation of Ofcom in 2003. Figures A2.2 and A2.3 contain public sector information licensed under the Open Government Licence v2.0. See National Archives record, Licence Summaries tab for the 2000 auction bids: https://perma.cc/T2MQ-YAF6.

[3] National Audit Office (2001).

[4] Binmore and Klemperer (2002), Cramton (2001), Klemperer (2002, 2004), Maldoom (2005), and History of GSM: Birth of the Mobile Revolution 'Story from inside the greatest 3G Auction on earth', https://perma.cc/329M-KQN4.

[5] Dyer, Kagel and Levin (1989), Charness and Levin (2009), Delgado et al. (2008), Filiz-Ozbay and Ozbay (2007), Roider and Schmitz (2012), and Malmendier and Tate (2015).

[6] Swann and Tether (2003).

[7] Börgers and Dustmann (2005).

[8] Cramton (2001, p.53).

[9] Maldoom (2005).

[10] For example, see European Commission (2016, paragraph 20).

[11] Cramton (2013, section 4).

[12] Reported, for example, by Mobile Broadband '4G auction and the possibility of litigation', 9 April 2012, https://perma.cc/K3PV-5AW2.

[13] Ofcom (2017, annex 4).

[14] One example of a negative incremental bid value was BT's winning bid of £340.431 million for 30 MHz of 2.6 GHz paired plus 20 MHz of 2.6 GHz unpaired (3xC + 4xE), compared to its *smaller* bid amount of £325.831 million for a package with *more* paired spectrum (4xC + 4xE).

[15] For an analysis of the 2013 auction suggesting straightforward bidding by Vodafone and some departures by Telefónica between clock and supplementary bids, see Levin and Skrzypacz (2016, pp. 2545–2547).

[16] Excess supply in the final clock round made changes in the spectrum allocation from the supplementary bids more likely (as indeed occurred). Therefore, the excess supply reduced operators'

exposure to price driving in the supplementary bids round, because it increased the risk that strategic bids intended to push up rivals' prices could inadvertently win, thereby reducing the incentive to engage in price driving.

[17] Ofcom (2015, paragraphs 2.151–2.159 and A6.139–A6.153).

[18] National Audit Office (2014).

[19] Ofcom (2014b), and Ofcom (2018b).

[20] Ausubel and Baranov (2017, section 2).

[21] Ofcom (2020a, section 6). Another provision turned out not to be relevant – principal stage winners of 20 MHz or less of 3.6–3.8 GHz spectrum would only be permitted to make assignment stage bids for either the top or bottom of the band. This approach was to reduce the risk of them making defragmentation by other operators more difficult.

[22] The sequence of operators reducing their demand reflected the bid mechanics of the SMRA, in which only non-standing high bidders needed to make new bids to maintain their demand. At the end of round 1, Telefónica was not selected as a standing high bidder (the choice was randomised) and it chose to reduce its demand from 100 MHz to 40 MHz in round 2 at a price of £21 million per 5 MHz, just 5 per cent above the reserve price – such a large change in demand is hard to reconcile with straightforward bidding. Telefónica's round 2 bids displaced Vodafone's standing high bids. Vodafone then chose in round 3 also to drop demand to 40 MHz, which partially displaced EE's standing high bids. Half of EE's demand, 40 MHz, remained as standing high bids so that, by making no new bids in round 4, it dropped the other 40 MHz of its demand to clear the market.

[23] The opportunity cost was zero for H3G's frequency location in the middle of the band, because EE could only win one location and it obtained its preference at the top of the band. No-one made a bid above zero for the bottom of the band, which was Telefónica's location in the band plan.

[24] Vodafone ended the auction and set the price of 700 MHz paired spectrum by dropping out of the band. Vodafone did not therefore benefit directly from a low price of this spectrum. It could, however, have perceived an indirect benefit from the potential for a low 700 MHz price to lead to a review and reduction in administratively-set annual fees for 900 MHz spectrum (a band where it held 35 MHz).

[25] Ofcom (2020a, paragraph 5.186).

[26] The regulator's limited information policy only reported to bidders the aggregate demand in a band in 20 MHz categories, which meant that specific rivals' bids were not visible. But bidders could still see excess demand drop by three categories (from less than 140 MHz to less than 80 MHz).

[27] The mechanics of the specific SMRA design for the 2018 and 2021 auctions meant that an operator could end up paying a price one increment higher than other winners. Vodafone paid £22.05 million per 5 MHz for its 3.6–3.8 GHz spectrum compared to others paying £21 million (and in the previous auction in 2018, Telefónica's price for its 3.4–3.6 GHz spectrum had been £39.7 million per 5 MHz compared to other winners at £37.8 million).

[28] Before the auction, the regulator also recognised that the 40/40/40 MHz allocation could be economically efficient – see Ofcom (2020a, paragraphs 6.48–6.50).

[29] With a CCA format in the 2021 auction, there could have been a vulnerability to price driving. H3G would have known that bids for smaller amounts were very likely to lose, but it could still set prices by being the highest losing bidder. However, if H3G had that motivation, it could have engaged in price driving in 3.6–3.8 GHz in the SMRA auction that was held, because it would similarly have known that the risk of it winning would initially have been very low. Instead of being interested in price driving, H3G may have anticipated obtaining a benefit from low 3.6–3.8 GHz prices in potentially triggering a review and reduction in administratively-set annual fees for its 3.4–3.8 GHz spectrum (where it held 120 MHz subject to such fees). This was similar to Vodafone's potential incentive in 700 MHz, although stronger here as H3G held a larger amount of fee-bearing spectrum and there was a closer connection between the auctioned and fee-paying bands.

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Note: 🔓 means an open access publication.

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