# 8. Choosing an auction format


## Summary

- This chapter explores in detail how the main formats for spectrum auctions operate, looking at: Simultaneous Multiple Round Ascending Auctions (SMRAs) with individual bids and a first-price rule; and Combinatorial Clock Auctions (CCAs) with package bids in an initial stage of multiple rounds, followed by sealed bids and a second-price rule; and less commonly used, a third format of sealed bids in a single round.
- Auction design for spectrum involves many trade-offs because there is no perfect design. To maximise economic efficiency, the regulator seeks to encourage straightforward bidding. Challenges include assisting bidders to refine their values through price discovery, to manage their bid strategies given their budget constraints, and to mitigate risks from substitution and aggregation effects.
- The regulator would also like to restrain incentives for strategic bidding, which can come in many forms including sniping, parking, bid shading, unilateral demand reduction, coordinated market division, signalling, freeriding, and price driving.
- Different auction formats and associated detailed rules involve varying choices in terms of transparency, simplicity, flexibility, and incentives for straightforward or the various types of strategic bidding.
- Choosing the most suitable auction format involves assessing their respective strengths and limitations, and taking account of the likelihood and importance of different risks in the specific circumstances of each auction.


Picking a suitable format is one of the most significant choices that a regulator can make for an auction, and it forms the heart of complex and crucial design analysis. The type of auction must be well suited to the specific circumstances prevailing. Three main formats are considered: SMRAs; CCAs; and sealed bids. For example, the UK regulator decided each of these formats was best suited to different high- and low-stakes auctions depending on the conditions, adopting an approach that can be


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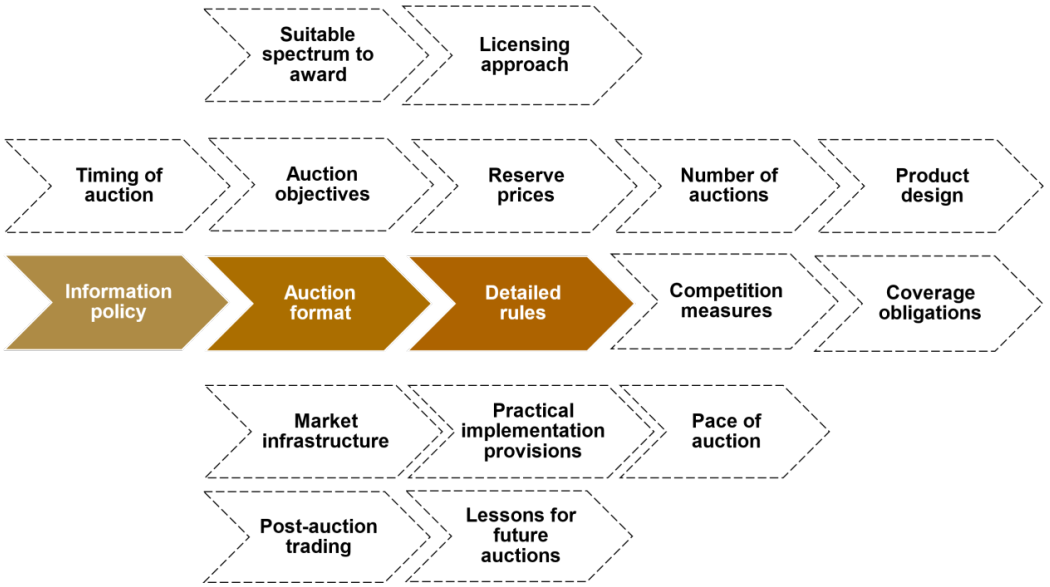
**Figure 8.1. Auction decisions assessed in Chapter 8**




Source: Author.

called 'horses for courses' – SMRAs for seven auctions, CCAs for three, and sealed bids for another three (see Annex A1). The second section analyses how choosing the auction format and the information policy – see Figure 8.1 – affect transparency, simplicity, flexibility, and the ability of companies to express their preferences for spectrum through their auction bids. The incentives for the many types of strategic bidding are considered in the third section, and then some of the detailed rules that can be consequential in the fourth section. The chapter's conclusion summarises each auction format's general strengths and limitations, and highlights how the choice of a suitable format can be guided by considering the likelihood and implications of different bidding risks in the conditions prevailing for any spectrum auction.

## 8.1 How the main auction formats differ

The three main auction formats differ in the nature of bids, the number of rounds, whether bids are sealed, and how the winners and prices are determined, as Figure 8.2 shows. A participating company can make individual bids for lots, some of which it can win and others lose, as in the SMRA format. Or there can be package bids for combinations of lots that win or lose in their entirety, as in the CCA format. Sealed-bid auctions can be specified either for individual bids or for package bids. Both SMRA and CCA formats are multiple-round auctions. The prices go up from round to round if the operators' demand for lots in a given category exceeds the available supply in the auction. By contrast, sealed-bid auctions only have a single round of secret bids. The CCA also includes a sealed-bid stage (the supplementary bids round), whereas the SMRA format does not. To identify the auction winners, the mechanics of the SMRA select the standing high bids after each round, and the winners

**Figure 8.2. A simplified comparison of auction formats**

| Auction element | SMRA | CCA | Sealed bid |
|---|---|---|---|
| **Nature of bids** | Individual bids for a number of lots at a price per lot in each category. | Clock stage: package bids for combinations of lots in each category at prices announced by the regulator. | As specified: either individual bids for lots and bid amounts in each category, or mutually exclusive package bids. |
| **Multiple rounds** | Ascending prices in any category where there is excess demand. | | Not applicable. |
| **Sealed bids** | Not applicable. | Supplementary bids round: many mutually exclusive package bids. | See top cell. |
| **Winner determination** | The standing high bids at the end of the auction (when there is no new bidding activity). | The highest-value combination of package bids (and at most one from each bidder). | The highest-value bids. |
| **Pricing rule** | Pay as bid (first price). | Based on highest losing bids (second price). | Can be either first price or second price. |

Source: Author.

are the companies with the standing high bids at the end of the auction. The winners in the CCA are the operators with the highest-value combination of package bids. Finally in Figure 8.2, the auction prices paid by the winners are given by the pay-as-bid or first-price rule in the SMRA, but the CCA uses the highest losing bids or second prices. Sealed-bid auctions can be specified to use either first or second prices.

Each format is better understood as a family of possible designs with many potential variants, some of which are discussed in this chapter.[1] Going beyond the basics, the performance of the auction depends on the overall effect of all the design features, including reserve prices, lot structure, and detailed rules such as those discussed in the fourth section.

## SMRAs

In the first round of an SMRA each company decides how many lots to bid for in each category at the reserve prices (or other initial prices as permitted in the auction rules). A category can comprise a single frequency-specific lot, or a group of generic lots (see Section 7.5). At the end of each round, the regulator specifies the standing high bids, and the provisional winning bids (which may use random selection if there are ties in categories). The regulator may also provide bidders with information on other bids or aggregate demand in each category. Standing high bids cannot usually be withdrawn, but they can be displaced by other bidders.[2] If demand equals or exceeds the available lots in a category, operators with unmet demand can then bid at a higher price and displace other firms' standing high bids from the previous round. In some versions of the SMRA, the bidder selects this higher price

(perhaps from a menu of price increments specified by the regulator). In the version used in the UK's 2018 and 2021 auctions, the regulator Ofcom specified the price.

The process of price increments and displacing standing high bids continues until there is no new bidding activity and demand for the spectrum in the auction no longer exceeds the available supply. As well as involving multiple rounds of ascending prices, the auction is simultaneous, meaning that no winners are determined for any category of lots until there is no new bidding activity across all categories. Because many spectrum auctions include multiple categories, an operator switching between them can restart bidding in a category that looked to have settled in an earlier round. For example, in the UK's 2018 auction, after 13 rounds of bidding in the 2.3 GHz category for 4G capacity spectrum, there was no excess demand – Telefónica was the only bidder still expressing demand with standing high bids on all four lots. There was no new bidding activity for the next 15 rounds. But in round 29, H3G switched some of its demand between categories, leading again to excess demand in 2.3 GHz. The price increased until H3G dropped out in round 54, and after that, there was no new activity in the category. But the possibility remained open as bidding still continued until round 67 for the other band of 5G spectrum (3.4–3.6 GHz). When the SMRA ends, the companies with the standing high bids are the winners and they pay the prices at which they made those bids (pay as bid).

Another format becoming used more frequently is a 'simple clock' auction (for example, it has been employed in Australia, Switzerland, Sweden, and the USA). In each successive round the regulator announces the price in each category, usually including generic lots, and the companies make their bids for a number of lots at that price until the demand matches the available supply of spectrum. Of course, the CCA format also includes a clock stage, but the simple clock auction differs by having neither package bidding nor a subsequent sealed-bid stage of supplementary bids, and by using pay-as-bid instead of second prices. The mechanics of the simple clock auction and the SMRA differ, but the version of the SMRA in the UK's 2018 and 2021 auctions with generic lots and round prices set by the regulator was functionally very similar to a simple clock auction (and it is sometimes called the 'SMRA-clock hybrid' format).[3] The simple clock auction runs faster because the price increases in every round when there is excess demand, whereas in the SMRA at lower levels of excess demand it can take several rounds to displace all the standing high bids at the previous price. (This was one of the reasons for the extremely slow pace of Portugal's 2021 auction.) In circumstances where the SMRA format is suitable, a simple clock design may also be appropriate or even preferred due, for instance, to its faster pace.

Clock auctions can also allow for exit bids or 'intra-round bidding' where an operator can specify an exit price for the lots it wants between the price levels set by the regulator for the previous and current rounds. A clock auction without exit bids was used in India's 2010 auction for 3G spectrum. It yielded high revenues, which the government had emphasised as an objective. However, theoretical and experimental analysis suggests that the standard clock with the additional information provided in exit bids generally performs better in securing an economically efficient allocation (and potentially higher revenue).[4]

### CCAs

A thumbnail sketch of the more complicated CCA format is that bidders place bids for packages of spectrum in two stages. (Annex B1 gives practical examples from the UK's 2013 auction.) The first,

clock stage continues at ascending prices in successive rounds until there is no excess demand in any lot category. The regulator provides feedback to bidders on the evolution of aggregate demand, assisting their package and price discovery. In turn, this discovery informs a bidder's sealed bids in the second stage, the supplementary bids round. Now each company can place many package bids which are mutually exclusive (i.e. at most only one of its package bids can win). The auction outcome takes into account bids placed in both stages. Winners pay prices set by the highest losing bids (second prices) to encourage straightforward bidding, because bidding below full value reduces the firm's chances of winning but may not affect the price paid.

Since the CCA is a combinatorial or package auction, the companies make package bids for lots in a number of categories. For example, in the UK's 2013 auction for 4G spectrum, an operator could place a bid for two lots of coverage spectrum (800 MHz band) and four lots of capacity spectrum (2.6 GHz band). The package bid for these six lots could either win or lose in its entirety. But it could not partially win, because the constituent elements of the package could not be considered separately (unlike the individual bids in the SMRA). *Price* discovery in the clock stage assists bidders to gain an understanding of the prices that they may ultimately have to pay to win spectrum. *Package* discovery helps operators to appreciate the packages of spectrum that they may have the best chance of winning, given their preferences, thereby providing guidance for their bids in the subsequent stage of supplementary bids. Because it is a simultaneous auction, the clock stage continues as long as there is excess demand in any lot category.

After the clock stage of CCA ends, there is the supplementary bids round. This is a single round of sealed package bids with no or little restriction on the number of mutually exclusive bids that a bidder can submit. For example, in the UK's 2013 auction Vodafone made 94 supplementary bids compared to only 11 by Telefónica (and both were a small fraction of the total number of feasible packages on which bids could have been made).[5] The supplementary bids round allows an operator to express preferences it did not get an opportunity to reflect during the clock stage, and so set out its demand function more fully. For example, suppose a bidder reduces its demand during the clock rounds, moving from a larger package in (say) round 50 to a smaller package in round 51, because prices in the new round were 25 per cent higher.[6] The operator might have been willing to pay 10 per cent more for the larger package than the price in round 50, but it did not get the opportunity to make this exit bid in the clock stage. It can, however, do so in the supplementary bids round.

Bidders can also now bid for different packages than they did in the clock rounds. The additional packages can include spectrum in excess supply at the end of the clock stage, as occurred with the 800 MHz and 2.6 GHz paired bands in the UK's 2013 auction (see Annex B1). In general, excess supply can arise in a package auction because the demand response to a price increment is not necessarily small – for example, it could lead an operator to drop demand for its entire package – or demand could be less than supply due to strategic bidding. Especially if there is excess supply in the last clock round, bids in the supplementary bids round could affect who wins spectrum and their winning packages – as happened in the 2013 auction, which concluded with all the spectrum being sold after operators made supplementary bids for the spectrum that had been in excess supply at the end of the clock stage.

To determine how much spectrum in which categories each winning bidder has won, the regulator solves a complicated optimisation problem. Total bid value is maximised by finding the combination of bids that is the best fit of the 'jigsaw' of package bids to the available supply of spectrum in the auction (taking at most one mutually exclusive bid from any operator).[7] One feature of the CCA is that the regulator could require a bidder to make good on any bid it has made in any round – for

instance, in the UK's 2013 auction there were 277 relevant package bids placed by seven bidders. So, an algorithm is developed to determine the combination of winning bids. If more than one combination yields the same maximum bid value, there are various tie-breaker rules, such as maximising the amount of spectrum sold. In 2013 the bidders ended up with very different winning packages after the supplementary bids round than at the end of the clock stage (see Annex B1).

For the regulator to find the efficient spectrum allocation from the combination of bids after the supplementary bids stage, there can be a problem of missing bids. Like a jigsaw with the wrong-shaped pieces, the packages of each bidder may not fit together so as to closely match the available spectrum – the fit could yield a more efficient allocation if it included packages for which no bids were placed. This 'package selection' problem would not arise if operators placed supplementary bids for all their profitable packages. But the experience in the UK's 2013 auction showed that in practice, bidders may only bid for a fraction of the feasible packages, and this pattern is commonly observed both in other auctions and in experiments.[8] Companies may face difficulties in deriving robust valuations for a large number of packages and ensuring meaningful and appropriate incremental bid values between them. The package selection problem can be alleviated if operators make sufficiently aggressive bids for their 'efficiency-relevant' packages, those in the more efficient allocations.[9] The process of package discovery during the clock stage can guide operators to identify these packages.

Supplementary bids can also affect prices, especially the prices paid by other winning bidders given the second-price rule, because they could be the highest losing bids (reflecting the opportunity cost of allocating spectrum to the winners). The CCA pricing rule is a more complicated version of a second-price rule called 'core pricing', which ensures that no losing bidder (as expressed through its bids) was willing to pay more than the auction price for spectrum won by others. Because the CCA is a package auction, prices are set for the winning packages not by band (as in the SMRA). In the UK's 2013 auction all the losing bids that determined the final package prices were made in the supplementary bids round. Total package prices based on highest losing bids were £2,341 million, much less than the amount in the winning bids of £5,249 million (and also much less than the prices in the final clock round, which amounted to £4,046 million). The size of the gap was due, for example, to missing bids from the jigsaw of package bids in the highest losing combinations that determined the second prices, so that nearly all the 2013 package prices included reserve price components. (See Annex B2 for examples from 2013 and further explanation of core pricing).

One potential consequence of the CCA pricing rule is that different bidders can be charged significantly different prices for the same or similar packages, a phenomenon observed in some CCAs in Canada, the Netherlands, and Switzerland, although it did not apply to the UK's 2013 auction.[10] The outcome can arise through straightforward bidding where opportunity costs genuinely differ, or due to differential strategic bidding between operators. When it happens, different operators paying different prices for similar packages can raise questions about the fairness of the outcome.

A variation on the CCA is the Combinatorial Multiple Round Ascending (CMRA) auction format. Like the CCA this retains package bidding in a clock auction, but it involves a pay-as-bid pricing rule (like the SMRA). Also, instead of a separate supplementary bids round, bidders can make bids for additional packages in each clock round.[11] This format has only been deployed on a few occasions, e.g. in Denmark and Norway. Another combinatorial auction format is 'hierarchical package bidding' which includes limited package bidding and simpler pricing rules.[12] It was designed for auctions with a large number of geographic licences and was used as part of the 700 MHz band auction in 2011 in the USA.

**Figure 8.3. Types of sealed-bid auction (with experience in the UK in two cells)**

| | Winner pays as bid (first price) | Winner pays highest losing bid (second price) |
|---|---|---|
| **Individual bids** | No UK example | 1785–1805 MHz auction in Northern Ireland in 2007 |
| **Package bids** | 2006 auctions: DECT guard band, and 412 MHz (and Norway in 2013) | No UK example |

Source: Author from Ofcom auction documents.

### Sealed-bid auctions

The bids from firms participating in a sealed-bid auction tell the regulator the number of lots they want in each category and the bid amounts in a single round. The bids are private, and an operator receives no information from the auction on the bids made by its rivals, either individually or in aggregate. The winners are the companies submitting the highest bids. The precise nature of the bids made and the prices paid depend on the type of sealed-bid auction. It can be specified as involving either individual or package bids, and either a first- or second-price rule, yielding the four types of sealed-bid auction shown in Figure 8.3. The UK regulator has only chosen a sealed-bid auction for lower-value spectrum, and two cells show examples. However, this format has been used elsewhere for high-stakes auctions, such as a multi-band auction in Norway in 2013 (a first-price auction with package bids for the 800 MHz, 900 MHz, and 1800 MHz bands).

## 8.2 Transparency, simplicity, and flexibility

The regulator seeks to discover operators' intrinsic values for the spectrum, and different auction formats can help or hinder bidders in expressing their preferences. In practice, the regulator has many design trade-offs to navigate between transparency, simplicity, and flexibility.

### Price discovery, budget constraints, and avoiding regret

Sealed-bid auctions lack transparency, because bidders obtain no information from the auction itself. In SMRAs and CCAs, by contrast, the multiple rounds can generate plenty of feedback, such as the levels of aggregate demand at different prices reported to participating firms. Multiple-round auctions seek to assist bidders and boost the economic efficiency of the outcome through price discovery. This can be especially important where there is common value uncertainty – in the extreme case of pure common value uncertainty, the item being auctioned is worth exactly the same to all bidders, but there is uncertainty what that value is, as with a closed jar of coins or an oil well. The problem in such an auction is the winner's curse - the winner generally only wins because it overbids through being too optimistic, e.g. bidding much higher than the face value of the coins in the jar.[13] Recognising this risk of winner's curse, companies may choose to bid more conservatively in sealed-bid auctions where

**Figure 8.4. An illustrative example of bid options for a budget-constrained bidder in a CCA**

| Bid strategy | Small package bid | Large package bid [excess over budget of 140] | Incremental value over small package | Issue |
|---|---|---|---|---|
| Intrinsic values | 100 | 190 [50] | 90 | Value of the large package exceeds the budget |
| (1) Bid the intrinsic values | 100 | 190 [50] | 90 | Risk of paying more than the budget for the large package |
| (2) Bid the lower of the intrinsic values and the budget | 100 | 140 [0] | 40 | Reduced chance of winning the large package |
| (3) Maintain incremental intrinsic value within the budget | 50 | 140 [0] | 90 | Reduced chance of winning the small package |

Source: Author.
Note: In CCAs only one mutually exclusive package bid per operator can be successful.

price discovery is absent. In most spectrum auctions there is no pure common value uncertainty, because there are important private value components which differ between bidders, depending on operators' existing spectrum portfolios or commercial strategies. However, there can be common value elements, such as the future expected commercial value of 3G services back in 2000 in the UK, when a winner's curse problem may have existed for the successful bidders despite multiple bidding rounds (see Annex A2).

CCAs involve a different type of lack of transparency about prices. The second-price rule is based on the highest losing bids which, by definition, are made by rival bidders and so are unknown to the winning firm in making its bid. (In the SMRA by contrast, the bidder knows the price it will pay if it wins, under 'pay as bid'). This uncertainty in CCAs about the price to be paid can complicate the choices for companies, especially if they are budget-constrained in the maximum amount that they can spend in the auction, as is often the case. To see the issues for budget-constrained bidders, the illustrative example in Figure 8.4 shows a firm that has an intrinsic value of 100 for a small package and 190 for a large package, but faces a budget constraint of 140. The firm's bid strategy options are also set out.

An operator could bid its intrinsic values for both the small and large packages in the supplementary bids round, even though a bid of 190 for the large package would exceed its budget by 50. Because the CCA uses a second-price rule, the operator could win the large package at a price much lower than its bid and still within its budget. But lack of certainty about prices at the time of bidding means that it could not guarantee such an outcome. Understandably many companies would not be comfortable taking a risk of winning at a price exceeding their budget.

A second strategy in Figure 8.4 is the operator bidding the lower of its intrinsic value and the budget: 100 for the small package and 140 for the large package. However, in a CCA the outcome is influenced by the incremental bid values, the difference in bids between different packages. These bids

tell the regulator that the operator's value for the large over the small package is only 40, instead of its much larger incremental intrinsic value of 90. An extreme version of this strategy was adopted by one bidder (BT) in the UK's 2007 CCA for the 10 GHz, 28 GHz, 32 GHz, and 40 GHz bands. BT made the same bid, perhaps its budget, for a range of smaller and larger packages – for example, £1.001 million for one lot of 32 GHz, and the same bid amount for a much larger package of six lots of 32 GHz plus two lots of 40 GHz. These bids were saying that BT's incremental bid value for the larger over the smaller package was zero, ascribing no value to an additional five lots of 32 GHz and two lots of 40 GHz. Unsurprisingly, BT did not win this larger package. The 2007 auction was an early instance of the CCA being held, and bidders had less understanding of bid strategies.

The third option for the hypothetical operator is bidding its budget of 140 for the large package. This is 50 below its value, but it can maintain its incremental intrinsic value of 90 by bidding 50 for the small package. This pair of package bids avoids a risk of facing a price above its budget or favouring the small over the large package. But the lower size of bids reduces its chances of winning the small package.

Each bid strategy has a disadvantage, so the company has to judge the best trade-off to make in the circumstances. In the SMRA, with its pay-as-bid rule, the price to be paid if it wins is transparent to the bidder, allowing it to manage the constraints of its budget more simply. For example, it could bid for spectrum in the large package until prices exceeded 140 and then bid for the small package if it was still profitable. In sealed-bid auctions the challenges for budget-constrained bidders depend on the precise characteristics of the auction – it is easiest for companies if there is a first-price rule and package bidding (because otherwise bidders face uncertainty about their prices or the maximum spectrum amounts they could win).

Auction formats also differ in the visibility of the provisional outcome before it is finalised. In the SMRA an operator knows when it is provisionally winning due to the standing high bids. If it is not, it always has an opportunity to 'bid back' before the outcome is finalised. However, both the sealed-bid auction and the supplementary bids round of the CCA involve sealed bids without an opportunity to bid back. This can lead to surprise outcomes for companies and bidder regret about the outcome and how it was reached.

## The different meanings of simplicity

Ironically enough, simplicity is far from a simple concept when it comes to auction design. Important questions are: simple for what and for whom? It can be simple to understand the mechanics of how an auction will operate, but still complex for operators choosing a bid strategy to manage various risks. Or it can be simple for the regulator but complex for bidders. The mechanics of SMRAs are simpler than for CCAs. The clock stage of the CCA operates more intuitively, but the supplementary bids round less so, and the winner and price determination involve complicated optimisation calculations. These more complex mechanics can cause problems for bidders, especially if they are less experienced or have fewer resources to obtain high-quality expert advice. However, the mechanics should be less of a concern for auctions involving only large and well-resourced national mobile operators. Also, the greater flexibility of the CCA assists a bidder to express its preferences more easily, whereas in the SMRA an operator has the complications of managing aggregation and substitution risks through its bid strategy (see the next two subsections). While there are complications for operators when bidding in the CCA, the SMRA is not as simple to bid in as it might superficially appear.

A sealed-bid, first-price auction highlights different aspects of simplicity. This auction format is generally very simple for a regulator to run, requiring no auction software platform, only a single round of bids, and simple determination of winners and prices. However, it is strategically complex for bidders. A bidder has only one chance to make a bid without any information from the auction on bids made by rivals, because all bids are sealed. Secondly, a company will not want to bid its full value because that is the price it will pay if it wins (due to a pay-as-bid rule) – making the firm indifferent between winning and losing. Instead, the firm faces a strong incentive to 'shade' its bid, namely reducing the bid below its full value, so that – if it wins – it makes a surplus (or profit) of the amount by which its value exceeds the price.[14] When deciding how much to lower its bid below full value, the operator has to judge the trade-off between reducing its chances of winning, and increasing its surplus if it does win. The chances of winning depend on the bids made by rivals, affected in turn by their values and the amount of bid shading they choose to engage in. So, each company has to second-guess its rivals, not only their values (which it may have some knowledge about if they operate in the same downstream market) but also their bid strategies.

An operator with a higher value relative to its rivals (sometimes called a 'strong' bidder) may gain more in increased surplus from greater bid shading than it loses in reduced chances of winning. This auction format thus tends to provide larger bid-shading incentives to strong bidders than to 'weak' bidders with lower relative values.[15] However, each bidder can work out that this differential trade-off could occur, which affects its view of rivals' bid strategies, and in turn that affects its own bid strategy. Deciding the best trade-off is, therefore, far from simple for a bidder. Norway's 2013 sealed-bid, first-price package auction is probably a practical example of differential bid shading. Surprisingly, one of the incumbent mobile operators, Tele2, was completely outbid by a new entrant, Telco Data. Tele2's underlying intrinsic values are not known, but it is plausible that it lost because it shaded its bids much more aggressively than Telco Data.[16] Tele2 subsequently chose to exit the market, by being acquired by another incumbent, TeliaSonera.

Is differential bid shading advantageous for downstream competition, because it provides a relative advantage to weak bidders who may be new entrants to the market? Decoding this question depends on the relevant circumstances and the trade-off between auction and output efficiency. On the one hand, for auction efficiency, the regulator wants the winner to be the operator with the highest value, and differential bid shading can put this outcome at risk. On the other hand, it can be beneficial for output efficiency if competition in the downstream market would be strengthened by the weak bidder winning the spectrum. This relative advantage to weak bidders was a reason that the UK regulator chose the sealed-bid, first-price auction format for one of its lower-stakes auctions in 2006 for 412 MHz spectrum.[17] However, the trade-off between auction and output efficiency sometimes makes this format undesirable, especially if there are already measures in the auction to promote downstream competition (see Chapter 9).

The superficial operational simplicity of the sealed-bid, first-price auction thus masks substantial strategic complexity, both for operators in deciding their bid strategies and for the regulator in achieving its auction objectives. The initial intention and allure of the CCA format was that it was the reverse: very complicated for the regulator but strategically straightforward for bidders. In addition, Chapter 10 shows how the CCA format can offer greater flexibility for a regulator to use the auction mechanism to generate better information on the opportunity costs of policy alternatives which can sometimes be important for public policy decisions. However, as the characteristics of the CCA have become better understood, in addition to the issues for budget-constrained bidders, it is now recognised as being less than straightforward for bidders due to the potential for strategic bidding set out

in the next section.[18] As regards the SMRA format, it involves pay-as-bid as in a first-price, sealed-bid auction, but the multiple rounds mean that a bidder has less need to second-guess its rivals' bids. An operator can observe the evolving situation across successive rounds and needs only to outbid the visible standing high bids of its rivals in order to win.

### Synergy values and aggregation risk

The CCA enables more flexible bids than the SMRA because package bidding allows operators to express synergies in their valuations. Synergies arise for complements, where the whole is worth more than sum of the parts. For example, if a company has 'stand-alone values' of 10 for item X on its own and 15 for item Y on its own, but winning both X and Y yields a value of 50, then it has a large synergy value of 25. Synergies in spectrum valuations are not unusual and sources include the following:

- Within-band synergies, due to technology that can make a block size that is twice as large have more than double the value – a factor relevant to the UK's 2013, 2018, and 2021 auctions.
- Cross-band synergies between coverage and capacity spectrum, which was especially relevant to the UK's 2013 auction. Both within-band and cross-band synergies were evident in some package bids in the CCA used for this auction, as in many of EE's bids (see Annex B1).
- Synergies between spectrum in different geographic areas, such as neighbouring locations to enhance wider coverage. This factor can be relevant for auctions with local or regional licences, e.g. in Australia, Brazil, Canada, India, and the USA (whereas most UK auctions have been for national licences).[19]
- Synergies from technical efficiencies of contiguous spectrum – a block of adjacent frequencies. Contiguity can be guaranteed in auctions with generic lot categories and an assignment stage (see Section 7.5).

In contrast to package bids, in SMRAs synergies cannot be directly expressed in bids. For within-band synergies, auction prices are linear in the same category, the same price for each lot. Synergies would mean that values are non-linear, such as valuing two lots at more than double one lot. For cross-band synergies, no package bid can be placed in the SMRA for the combination of lots in different categories. So, the operator has to manage through its bid strategy the complications of the resulting exposure or aggregation risk. The operator could split its synergy value between its individual bids by bidding more than the stand-alone value of the lots (the value without any synergies). It could do so in the hope of winning lots in both categories, but it would face the risk of being successful in one category but not the other. If the bids in only one of the categories were successful, the operator would end up making a loss by bidding and paying a price above its stand-alone value for those lots. On the other hand, the operator would reduce its chances of winning if it failed to include the synergy value in its bids.

The extent of the problems from aggregation risk depends on the size of the synergies. If they are not large, aggregation risk is less difficult for bidders to manage, and so may not be an important consideration for the regulator's choice of auction format. In addition, the risk can be reduced with less price uncertainty, and bidders can sometimes affect the evolution of prices in the auction through their bid strategies. For example, in an SMRA with bid increments selected by the bidder, an operator could seek to reduce uncertainty about relative prices between categories by equalising the speed of

market clearing in different categories by using jump bids (which increase the bid amounts by more than the minimum bid increment) in some categories.[20]

### Substitution risks

One of the rationales for a simultaneous auction is that different categories may include spectrum blocks which are substitutes for an operator, so that it can switch its demand in the auction between categories based on their relative prices. However, in an SMRA a bidder can be constrained in switching between categories, leading to substitution risk. Take the simple example of a bidder in category Y who gets no value from winning a single lot, a value of 20 for two lots, no additional value for more than two lots, but similar values for substitute spectrum in a different category, Z. Assume that the company continues to bid for two lots in category Y until the price reaches 10 per lot, and in that round only one of its two bids is made a standing high bid. Standing high bids are provisionally winning and as such they cannot usually be switched to another category. The bidder is now stuck in category Y – it does not want to win one lot at a price of 10 because it has no value for a single lot. The price will go up in the next round as there is excess demand, but the company does not want to bid for two lots at the higher price which is above its value. Of its two bids, it can switch its non-standing high bid to category Z where prices are lower, but not its standing high bid in Y. The best the operator can do in this case is hope that it is displaced by new bids in Y from rivals in the next round.

In this example the problem arises due to the combination of the bidder having synergies (value of zero for one lot and 20 for two lots), the SMRA involving individual not package bids, and the standing high bid mechanism. Here, substitution risk exacerbates aggregation risk. The problem in the example does not arise in the CCA because the bidder can switch its demand between categories during the clock stage and make multiple package bids in the supplementary bids round to express its relative preferences (e.g. the firm could bid 20 for a package of two lots of category Y, and 20 for a package of substitute spectrum in category Z).

There are ways to mitigate substitution risk in SMRAs, but all have downsides. For example, in the UK's 2018 auction, a bidder was allowed to withdraw its standing high bid in a situation like the illustrative example. However, withdrawals can also be used for strategic bidding, such as to provide a signal to other bidders.[21] In the extreme, if withdrawals can be made without penalty, bids are no longer commitments and there is a fundamental problem for the efficiency of the auction.[22] So, the 2018 design included serious consequences for the operator if its withdrawal led to the spectrum being unsold.[23] The result is that substitution risk remains in the SMRA, even after attempts to introduce auction features to mitigate it. This is another source of complexity that an operator has to manage through its bid strategy.

## 8.3 Incentives for strategic bidding

Operators may seek to improve their own outcome or worsen their rivals' outcomes by departing from straightforward bidding in the ways described in Figure 8.5. Some types of strategic bidding are harmful for auction and/or output efficiency, such as strategic investment which is designed to distort the allocation of spectrum and weaken downstream competition. For others, the effect depends on whether they distort the spectrum allocation, either directly or indirectly as a by-product of altering auction prices (either to lower payments for the strategic bidder, or to raise them for rivals). However,

**Figure 8.5. The nine main types of strategic bidding**

| | |
|---|---|
| **Sniping** | Hiding demand before swooping in at the end to win (see Section 3.3). |
| **Bid shading** | Lowering the bid amount below intrinsic value to reduce the price paid (see Section 8.2). |
| **Parking** | Bidding for lots in a category, not to win them but to maintain 'eligibility'. Parking prevents the activity rule from reducing the amount of spectrum that the company can bid for in subsequent rounds (see Section 8.4). |
| **Strategic demand reduction** | Bidding for less spectrum than indicated by intrinsic value, to reduce the price paid. |
| **Market division** | Coordinated demand reduction by a set of bidders, to reduce the price paid. |
| **Signalling** | Using bids to indicate information to rival bidders, including invitations to coordinate or threats to punish. |
| **Freeriding** | Smaller bidders freeriding on each other in seeking collectively to outbid a larger bidder, which can lead to a 'threshold' problem. |
| **Price driving** | Bidding above intrinsic value, not to win the spectrum but to increase the price paid by rivals. |
| **Strategic investment** | Winning spectrum so as to deny it to rivals and weaken downstream competition (see Chapter 9). |

Source: Author.

in general, strategic bidding jeopardises the regulator's desire to incentivise bidding to achieve efficient outcomes.

Sniping involves a bidder being a 'snake in the grass', leaving no time for others to respond – it was noted earlier in Section 3.3. Bid shading was discussed in the previous section. And strategic investment is central to the analysis of competition measures in Chapter 9, so I hold it over until then. Therefore, in this section (and the next one on detailed rules) I focus on the other six types of strategic bidding.

### Strategic demand reduction

We saw in the earlier subsection on the different meanings of simplicity that in sealed-bid, first-price auctions, bid shading is a type of unilateral demand reduction, adopted by the bidder in order to obtain a lower price. Similarly, in SMRAs there is a significant risk that a strategic operator bids less than its true demand at the price in the round. Although it could win less spectrum by doing this, the firm wants to do so at a sufficiently lower price that the strategy is profitable. The company hopes to win all the lots it is bidding for at the lower price (which is linear, the same price for each lot in a category), instead of bidding straightforwardly for more lots, which is likely to lead to higher prices.[24] If bidders expect to be important enough in the auction to influence the outcome, there is a strong incentive for this kind of unilateral strategic demand reduction – as in spectrum auctions with small numbers of sizeable bidders: in the UK four in 2021, five in 2018, and seven in 2013 (although two of these would have been regarded as weak bidders by the large national mobile operators).[25] Firms using strategic demand reduction can lower both auction prices and economic efficiency if they change the spectrum allocation compared to intrinsic-value bidding.[26]

The CCA format is far less vulnerable to strategic demand reduction because of the different pricing rule. Linear prices are used in the clock stage, but the final prices after the supplementary bids round are non-linear. For example, the price of the first lot won by an operator can be different from the price of a second lot – in the UK's 2013 auction Telefónica's price of £550 million was composed of £325 million for one 10 MHz block of 800 MHz and £225 million for the other. Non-linear prices mitigate incentives for strategic demand reduction because a bidder can bid for a larger package without that necessarily raising the price of a smaller package.[27]

A different type of demand reduction can occur in CCAs if smaller bidders compete collectively against a single larger bidder, such as when four smaller bidders, each wanting one lot, are bidding against one larger bidder for four lots. Such a situation can set up a 'threshold problem' where smaller bidders have incentives to freeride, each relying on the others to bear a bigger part of the cost of outbidding the larger bidder, and so failing to win.[28] The threshold problem can be a relevant concern, although it 'has been found not to interfere with [economic] efficiency in many experiments'.[29]

## Market division and signalling

The strategy of market division involves tacit collusion between operators for coordinated demand reduction, so that companies implicitly agree to restrict competition between them, seeking to all win spectrum at a lower price. It can be profitable for an individual firm to defect from (or cheat on) the tacit agreement so as to win more lots at a low price. But the coordinated approach can be maintained if the bidders can trust or rely on each other to stick to the tacit agreement, or if they have a way of punishing bidders that defect.[30] Operators can try to signal to each other through their bids, providing either invitations to coordinate or threats to punish perceived cheats. In Germany's 1999 auction there was an ingenious example of a signal inviting market division. Ten licences were available, the minimum price increment between rounds was set at 10 per cent, and larger jump bids were also permitted. Mannesmann, one of the two largest telecoms operators in Germany, started in the first round with a jump bid for the first five licences at a price per MHz of DM20 million, and for the second five at a price of DM18.18 million. The other large operator, T-Mobil, recognised the signal, and bid a 10 per cent increment for the second five licences taking their price to DM20 million, and the auction ended after only two rounds with an equal split of all licences at the same price between the two firms.[31]

After each round of an SMRA, the feedback to bidders of demand information can also provide triggers and opportunities to signal. A focal point makes coordination much easier because the coordinating bidders are then aiming for mutually consistent quantities of spectrum. In the UK's 2018 and 2021 auctions, Ofcom's choice of information policy limited the demand feedback to bidders to ranges of aggregate demand, not exact levels, in an effort to make signalling between bidders harder, but these two auctions played out very differently.[32] There was strong competition between bidders in the 2018 auction. However, in 2021 there was an especially clear and obvious focal point of 24 lots split equally between three operators for the 3.6–3.8 GHz band, and the evidence suggests that market division occurred (see Annex A5). A focal point is rarely as clear-cut, and normally there are at least some sources of doubt about it. A category can be split between bidders in different ways, or other sources of asymmetry can disrupt tacit agreement – for example, pre-existing spectrum portfolios can mean that bidders want or need to acquire different amounts. Or a bidder

sitting outside the coordinating firms may break up their implicitly agreed outcome. Consequently, market division is far from inevitable, but it is a much larger risk in SMRAs than in CCAs or sealed-bid auctions.

The CCA format is generally less vulnerable to market division, because the supplementary bids round allows a bidder to cheat on the tacit agreement without a risk that it will be punished by other bidders when they find out. By then it is too late – there is no opportunity to bid back, and the auction is over.[33] This feature is also present in sealed-bid auctions, which additionally have no open stage when signalling can even be attempted during the auction.

### Price driving

An operator may bid above its intrinsic value, not to win the spectrum lots but instead to push up the price that its rivals have to pay for them (sometimes also called 'spiteful' bidding). There could be a number of rationales for price driving, such as:

- Using up more of rivals' budgets in a category where the price-driving bidder does not want to acquire spectrum, so as to increase its chances of winning spectrum in a different desirable category (sometimes called 'budget binding').
- Draining rivals' financial resources to weaken them as competitors in downstream markets.
- Making the bid team look good to senior management, or the company to stock market analysts, by obtaining spectrum more cheaply than rivals.

Using up rivals' budgets can adversely affect auction efficiency if it inefficiently changes the spectrum allocation. However, if it only affects the price, it does not have a direct effect on economic efficiency – the winning bidders pay more than in the absence of price driving, but the price is still within their valuations of the spectrum (otherwise they would stop bidding and let the price-driving bidder win). Draining rivals' resources could affect output efficiency, for instance by depleting internal financing for new network investments. However, except in special cases, the scale of price driving would normally not be large enough, and rivals' resources fragile enough, for a substantial effect to result (see Section 7.2). The last rationale of looking good may have little or no economic efficiency consequences.

For similar reasons, the upsides for a price-driving bidder will depend on the circumstances and often may not be large, and even a modest downside for a bidder can have a significant impact in deterring price driving. The most obvious downside is the risk that the price-driving strategy fails, so that the strategic bidder inadvertently wins spectrum it did not want and incurs a loss. That risk is lower if the operator is well informed about the strength of rivals' values. For instance, a possible case of price driving occurred in the UK's 2018 auction, when H3G bid for 4G capacity spectrum (2.3 GHz band) which it was well known that Telefónica strongly wanted to win (see Annex A4). If things are not that clear, however, the regulator can make it harder for strategic bidders to know how far to push a price-driving strategy, by limiting their information about whom they are bidding against and the level of excess demand. Overall, price driving can occur in any of the auction formats. But it can be a larger risk in CCAs depending on the detailed rules, as explained in the analysis of activity rules in the next section.

## 8.4 Detailed rules

Each auction format is more akin to a family of possible designs than a single set of boiler-plate provisions. So, another set of regulatory decisions concern the detailed accompanying rules that can substantially affect how well the auction performs.

### Activity rules

One constraint on bidders is the activity rule, a feature of multiple-round spectrum auctions since the first SMRA in 1994 in the USA. The rule prevents a bidder from increasing its demand as prices rise across the multiple rounds, on the basis that a straightforward bidder reflecting its intrinsic value for spectrum would either keep its demand for spectrum the same at higher prices or reduce it. The activity rule incentivises more straightforward bidding, assisting price discovery and economic efficiency, and it prevents 'sniping'. In auctions with multiple categories the activity rule applies to eligibility points specified by the regulator for each category. A bidder can switch between categories in a round as long as the eligibility points in its new bids do not exceed its current activity level, usually set as the eligibility points of its bids in the previous round.[34] A firm can sometimes have an incentive to depart from straightforward bidding so as to maintain its eligibility points and its range of options. An example is 'parking' eligibility by bidding in a category of lower-priced lots where the operator does not want to win spectrum, but allowing it later on to switch the eligibility points into another, desired category – a pattern of bidding that can disrupt the price discovery achieved by the auction.

Activity rules are much more complicated in CCAs, because they link bidding between the clock stage and the supplementary bids round. The logic of CCA activity rules is to restrict future bids to be consistent with earlier bid decisions. For example, take the case of a clock round when a company had enough eligibility points to bid for a larger package, but chose instead to bid for a smaller package. The activity rule then requires that any bid for the larger package by the operator in its subsequent supplementary bids needs to be at an amount consistent with its revealed preference for the smaller package – called the 'relative cap' activity rule in the UK's 2013 auction. (Annex B3 gives a more detailed account, including practical examples.) Tighter activity rules are possible and have been used in auctions in Canada and Ireland. These tighter rules could largely determine the outcome in the clock stage, leaving only the sale of any lots in excess supply at the end of the clock stage for the supplementary bids round – affecting the balance of action in CCAs between the clock and supplementary stages.

As ever, there is a trade-off. Utilising tighter activity rules in a CCA design can assist price and package discovery, incentivise more straightforward bidding, and make the outcome more predictable for operators. Yet it can also run the risk of unduly constraining bidders. For example, if there is common value uncertainty, an operator would like to update its spectrum valuations based on price discovery in the auction. But very tight activity rules can be unforgiving of such modifications and could prevent some bids based on the updated values.[35] More generally, tight activity rules can punish any mis-steps that a bidder makes earlier in the auction, by restricting its bid options later on. Bidding in the CCA is easier if the operator has a clear budget and spectrum valuations before the start of the auction. However, expected values are subject to uncertainty and can depend on events in the auction itself (see Section 7.1). Similarly, a firm's budget constraint is not necessarily a single hard figure specified in advance and could in practice be softer, evolving during the auction process.

The complexities of activity rules can be especially difficult for less experienced bidders in CCAs. By contrast, the simpler rules in SMRAs allow bidders to adapt their approaches more easily, and only reach their final views on budgets and spectrum valuations as the auction proceeds.

Tight activity rules in CCAs can also increase the risk of price driving in the supplementary bids round by reducing the downsides of this strategy. A strategic bidder may face a lower risk that its price-driving supplementary bid will win, because the tight activity rules significantly limit the potential for changes in the spectrum allocation in the supplementary bids round, compared to the final clock round. For instance, if there were no excess supply at the end of the clock stage, some activity rules would guarantee that supplementary bids would not change the allocation, so that price-driving bids would then be free of the risk of winning undesired lots. Price driving could cause the final auction prices to become closer to those in the last clock round — indeed this could be part of the regulator's rationale for the tight activity rules so as to assist price predictability and budget-constrained bidders.[36] However, if price driving is expected by operators, it could reintroduce larger risks of strategic demand reduction into CCAs, by making the final auction prices closer to the linear prices in the last clock round.[37]

Activity rules can, therefore, be especially important – and complicated – in the CCA. The auction design choice can require delicate trade-offs to be struck between alternative risks, like improved price and package discovery in the clock stage as against increased risk of bidders having incentives to deviate from straightforward bidding.

### Setting eligibility points

In auctions with a number of lot categories, such as for multiple spectrum bands, the regulator has to specify the eligibility points for a lot in each category. Where categories include substitute spectrum, choosing eligibility points that allow operators to switch back and forth between categories as their relative prices change has the advantage of facilitating straightforward bidding based on intrinsic values. Annex B3 shows how the regulator's choices of eligibility points for the UK's 2013 auction had mixed success, working well for switching between some bands but not between others, leading to adverse effects on price discovery. The price discovery in 2013 could have been improved by setting eligibility points based on suitable relative *amounts* of spectrum that operators might wish to switch between categories, instead of on their relative *reserve prices*.

Setting eligibility points to allow easier switching between categories can unintentionally assist strategic bidding. For instance, an operator might price drive in category X and then drop out of the category if it looks too risky, and focus on another category, W, where it wants to win spectrum. The price-driving attempt can be simpler if the bidder is able to switch demand easily between X and W. So, any decision on eligibility points needs to strike a balance between making strategic bidding more difficult while also facilitating switching that reflects straightforward bidding.

### Limits on bid or price increments, and other rules

In the early SMRAs in the USA, operators had a free choice of the bid increment they wanted to use – this turned out to be a regulatory mistake. Companies quickly worked out how to use the freedom to make signals to rival bidders. For example, a jump bid (increasing the price by a large amount)

could signal aggressive intent and send a message to rivals to stay away. Also, lots were numbered, which some companies used as strategic signals (referred to as 'code bidding'). For example, a firm could choose a bid amount that mirrored the number of a lot that it wanted rivals to stay away from, or to signal a threat that it would start bidding on that lot if rivals continued to compete in its home territory.[38] Regulators could use their information policy to try and obscure some of these signals. However, a more straightforward solution is to restrict the companies to bid increments from a menu of options specified by the regulator. Alternatively, the regulator, not the bidders, could set the prices in each round as in simple clock auctions or in the UK's 2018 and 2021 SMRAs.

There are many further options and choices for the regulator in nailing down the details of the auction design so as to mitigate various risks, without being able to eliminate them altogether and often creating a side-effect of exacerbating a different problem. For instance, SMRA designs often include waivers for each bidder (up to three in the UK's 2000, 2018, and 2021 auctions), allowing it to sit out a round and make no bid without losing its eligibility. As well as giving bidders some leeway if they have technical difficulties and are unable to place a bid, it is a feature that partially mitigates substitution risk. For example, a 'partial standing high bidder' with fewer standing high bids than the number of lots it bid for in a category can sit out a round to see if its standing high bids are displaced before making its next bid decision. Three operators in the 2018 auction used one of their waivers. Similar to other features, waivers can be used strategically such as for signalling, so regulatory judgement is needed about the trade-off when deciding whether and how many waivers to include.

Another example of a detailed rule is the approach to selecting standing high bids in the SMRA format when there is excess demand in a category. In the UK's 2018 and 2021 auctions, the regulator ranked the bidders in each category (by bid price and then by random choice), with all of an operator's bids in that category being designated as standing high bids up to the available number of lots – instead of, for example, designating all active bidders with some standing high bids. Ranking by bidders ensured that there was at most one partial standing high bidder in each category, thereby limiting the number of operators exposed to aggregation or substitution risk in any round.

## 8.5 Conclusions: the strengths and limitations of auction formats

Figure 8.6 summarises the strengths and limitations of different approaches in combatting bidding risks discussed here (one per row). The 'traffic light' colour coding is to assist regulatory judgements about pros and cons, rather than to designate any one format as 'better'. Red cells denote a weakness that is hard to mitigate, either by an operator through its bid strategy or by the regulator through additional auction features. Amber cells indicate a limitation but one that can be mitigated to some extent. Green cells indicate a strength of the format. The grouping of rows shows four main types of risks – to determining outcomes, information deficits, ability to make intrinsic value bids, and strategic bidding.

Of course, within each format there are many possible variants such as, for SMRAs, using frequency-specific or generic lots, or simple clock auctions. Figure 8.6 only captures general tendencies and it entails making judgements and assuming auction features that can mitigate or exacerbate different risks, such as generic lots and suitable information policy and competition measures. In addition, the colour coding embeds views with which reasonable people could disagree, and it encompasses a range so that there could still be material differences between formats with the same colour for a bidding risk.

**Figure 8.6. How the three main auction formats fare in addressing bidding risks**

| Bidding risks [in some cases, with an auction feature that significantly mitigates it] | SMRA | CCA | Sealed-bid, package, first price |
|---|---|---|---|
| **Concern about how the outcome is determined** | | | |
| Unfairness, e.g. differentiated prices | Strength | Limitation | Limitation |
| Bidder regret | Strength | Limitation | Weakness |
| Navigating complicated mechanics | Strength | Weakness | Strength |
| **Lack of information during the auction** | | | |
| Price discovery / Risk of winner's curse | Strength | Strength | Weakness |
| Package discovery [information policy] | Limitation | Limitation | Limitation |
| Managing budget constraints [CCA activity rules] | Strength | Limitation | Strength |
| **Inability to bid intrinsic value preferences** | | | |
| Aggregation risk | Limitation | Strength | Strength |
| Substitution risk | Limitation | Strength | Strength |
| Opportunity costs of policy alternatives | Limitation | Strength | Limitation |
| **Risk of strategic bidding** | | | |
| Sniping [activity rules] | Strength | Strength | Strength |
| Parking | Limitation | Limitation | Strength |
| Demand reduction (unilateral) / Bid shading | Weakness | Strength | Weakness |
| Market division [information policy] | Limitation | Strength | Strength |
| Signalling [information policy] | Limitation | Limitation | Strength |
| Threshold problem | Strength | Limitation | Limitation |
| Price driving [information policy] | Limitation | Limitation | Limitation |
| Strategic investment [competition measures] | Limitation | Limitation | Limitation |

Source: Author.
Note: For sealed-bid auctions, the combinatorial, first price version of the sealed-bid auction is used (simply because it has been implemented twice in the UK and also in a multi-band auction in Norway).

Comparing the formats as indicated in Figure 8.6:

- SMRAs make some aspects of bidding simpler for operators. Aggregation and substitution risks remain, but an operator can often mitigate them to an extent (though not eliminate them) through its bid strategy. However, it is hard for a regulator to mitigate the risks of demand reduction. A limited information policy can attempt to make market division more difficult, but it remains a risk, especially if there is a very clear focal point even with a limited information policy, as in the UK's 2021 auction.
- CCAs avoid exposing a bidder to aggregation and substitution risk, and tend to have lower risks of demand reduction and market division. But various other risks (like those arising from

budget constraints) can only be partially mitigated, because the final auction prices are not transparent when bids are made. Also, some of the mechanics can be especially complicated, such as the activity rules.
- Sealed-bid auctions derive both strengths and limitations from having no open stage of bidding. Operators cannot easily achieve signalling and market division which damage economic efficiency. But bidders may be more exposed to risks of regret and winner's curse. There are strong bid-shading incentives (if a first-price rule is used). The strengths shown for aggregation and substitution risk in Figure 8.6 are due to package bidding being assumed.

Totting up the number of reds, ambers, and greens for each format, so as to mechanically derive the 'best' format to choose would be silly because views and implicit assumptions are embedded in the colours. Also, it is crucial for the regulator to consider how the circumstances of each auction affect the likelihood of the different risks being present – for example:

- If there are large common value components, the risk of winner's curse increases, as in the UK's 2000 auction. A sealed-bid auction manages that risk least well.
- If significant cross-band synergies are expected, aggregation risk is likely. It is avoided by package bidding, as in the CCA design used for the UK's 2013 auction.
- If there is a clear focal point, market division becomes a more likely risk, especially with SMRAs, as for the 3.6–3.8 GHz band in the UK's 2021 auction.
- If inexperienced bidders will participate, they may find the CCA mechanics challenging, even with significant bidder education.

The regulator needs also to combine these considerations with an understanding of the implications for achieving the objectives of the auction, especially economic efficiency. Some issues of keen interest to operators, such as risks of price driving, can be less important for the regulator, because the implications may be less about the size of the cake (economic efficiency) and more about the slices obtained by each operator.

The UK regulator's format choices for its four high-stakes auctions illustrate the analytical framework set out here of bidding *risks*, their *likelihood*, and the *implications*:

- SMRA in 2000: The SMRA format allowed operators to substitute between the larger and smaller licences, and to learn from each other in the price discovery achieved over the rounds of bidding.
- CCA in 2013: Despite the 'heavy machinery' of its more complicated mechanics, the CCA format enabled bidders to express synergies in their bids, including cross-band between coverage and capacity spectrum. It also allowed a flexible approach to competition measures (see Section 10.1).
- SMRA in 2018: In the absence of large cross-band synergies, the complications of a CCA were not needed. The relative strengths of the SMRA format were more prominent, such as being easier for budget-constrained bidders and involving less risk of bidders being surprised by the outcome.
- SMRA in 2021: There were similar reasons to choose an SMRA format as in 2018. Although this auction included both coverage and capacity spectrum, cross-band synergies were not significant in light of operators' much larger spectrum portfolios than in 2013. While there

was a clear focal point for market division in the 5G capacity band (3.6–3.8 GHz), it was also a plausible efficient spectrum allocation, making that outcome much less concerning.

The US regulator has sometimes preferred simple clock auctions that are functionally very similar but faster than the SMRA-clock hybrid format used for the UK auctions in 2018 and 2021, with generic lots and prices set by the regulator. Speed of the auction process is more important in the USA, given the much larger number of lot categories for geographic areas. In addition, over time the design possibilities evolve through improvements and step changes, such as the invention of new auction formats. Good auction design depends on judging the large number of trade-offs based on a rich understanding of both the factual circumstances and the consequences of selecting different combinations of auction features.

## Notes

[1] For example, DotEcon (2019, annex 1) describes variants such as standard SMRA, augmented switching, SMRA-clock hybrid (used in the UK's 2018 and 2021 auctions), simple clock, clock-plus, CCA (used in the UK's 2013 auction), enhanced CCA, hierarchical package bidding, and Combinatorial Multiple Round Ascending (CMRA).

[2] The auction rules may permit bid withdrawals – for an example, see the discussion of substitution risks in Section 8.2.

[3] The precise degree of functional similarity between SMRA and clock auctions depends on the detail of the rules in each, such as respective rules on switching demand between categories. For the theory of the SMRA and clock formats, see Milgrom (2004, sections 7.2–7.3).

[4] Cramton et al. (2012).

[5] The number of so-called permissible packages for each bidder in the UK's 2013 auction is still confidential because it depended on bidders' (unpublished) initial financial deposits, which determined how much spectrum they could bid for at the start of the auction. However, it could have been in the thousands as the theoretical maximum was 3,149 packages.

[6] Ofcom did indeed set a price increment as large as 25 per cent for the 2.6 GHz unpaired category in the last few rounds of the 2013 auction clock stage. This risked causing excess supply, but was in the full knowledge that there would be opportunities for any potentially unsold spectrum to be awarded in the supplementary bids round.

[7] The outcome of the CCA is a hard computational problem, known as 'multi-dimensional knapsack' optimisation. The regulator has to choose the combination of package bids (at most one from each bidder) that fit into the metaphorical knapsack of the available spectrum to yield the highest total bid value.

[8] Bichler, Shabalin, and Wolf (2013) suggest that bidders use simple heuristics to select packages, and focus on a small number with the largest synergies.

[9] Kagel, Lien, and Milgrom (2010), and Kagel, Lien, and Milgrom (2014).

[10] Mochon and Saez (2017, p.321).

[11] See DotEcon 'The Combinatorial Multi-Round Ascending Auction (CMRA): proposal for a new auction format', February 2016, https://perma.cc/N25L-6S3L.

[12] Goeree and Holt (2010).

[13] Thaler (1988).

[14] The discussion here is bid shading incentives where a bidder knows its own private value but does not know rivals' bids. Another reason for bid shading is to reduce the risk of the winner's curse where there is common value uncertainty.

[15] Ausubel et al. (2014).

[16] See Capacity Media 'Norwegian mobile operator Tele2 has failed to secure any additional 3G and 4G spectrum in Norway's auction', 9 December 2013, https://perma.cc/K25H-7PYS. The auction outcome is shown in Ofcom (2015, annex 8, pp.179–180).

[17] Ofcom (2006a, paragraph 4.35, third bullet point).

[18] Levin and Skrzypacz (2016).

[19] For evidence of geographic synergies in the USA's auctions, see Ausubel et al. (1997).

[20] Milgrom and Vogt (2021, pp.14–15) discuss the largest jump bid in the history of spectrum auctions (almost $750 million) in a 2006 auction in the USA.

[21] Cramton and Schwartz (2000).

[22] In the 2018 auction, withdrawals could only be made by a partial standing high bidder with fewer standing high bids in a category than the number of lots it bid for (as in the illustrative example). Even so, there was still some potential to use withdrawals for strategic bidding.

[23] The withdrawal penalty can be specified as the revenue lost by the bidder withdrawing. In the UK's 2018 auction, a penalty applied only if the spectrum was unsold. If so, there was an especially stringent approach because the bidder had to pay an amount equal to the price of the withdrawn bids, or twice the price to buy the unsold spectrum. The economic logic was it exposed the withdrawal bidder to (roughly) the opportunity cost of the withdrawn bids, to be taken into account when it decided whether or not to withdraw its standing high bids. This opportunity cost was 'the value of the spectrum to other bidders which the withdrawal bidder outbid to become standing high bidder on these lots', Ofcom (2017, paragraph 8.21).

[24] In this respect the bidder's incentive to reduce demand and the auction price is analogous to a monopolist maximising its profit by restricting supply.

[25] Post-auction acquisition of the auctioned spectrum through trading or mergers could also enhance the profitability of demand reduction – see Pagnozzi and Saral (2019).

[26] For examples of demand reduction in spectrum auctions, see Ausubel et al. (2014, p.1392).

[27] To continue the analogy with monopoly pricing, if the monopolist can set non-linear prices, its incentive to restrict supply is mitigated. This is because it can increase profits by selling additional units of output beyond the monopoly level of supply at a lower price without reducing the higher price on the previous output.

[28] Bykowsky, Cull and Ledyard (2000).

[29] Kagel, Lien and Milgrom (2014, p.229).

[30] Cramton and Schwartz (2000).

[31] Milgrom (2004, pp.29–30), and Jehiel and Moldovanu (2003, box 4, p.280).

[32] For an analysis suggesting the FCC's more limited information policy over time reduced bidders' ability to tacitly collude, see Bajari and Yeo (2009). For a contrary view favouring transparency in the information policy, see Bichler, Gretschko and Janssen (2017).

[33] However, if bidders are playing a bigger game, they may still have the threat of punishing cheats in other contexts or in future auctions.

[34] There are possible variants to the activity rule providing more flexibility, such as phasing in the requirement (although this has not been adopted in UK auctions).

[35] For types of updating of values which are and are not permitted by different activity rules, and a suggestion that tight activity rules can be 'saving the bidder from itself', see Ausubel and Baranov (2020b, pp.482 and 485–87).

[36] The design for a multi-band CCA in Ireland went one step further to assist predictability. It provided bidders in each clock round with their 'exposure prices', the maximum potential price for their package if the clock stage were to end in that round (with demand equal to supply) – see ComReg (2021, paragraphs 4.113–4.118 and annex 10).

[37] Levin and Skrzypacz (2016).

[38] Cramton and Schwartz (2000).

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Note: 🔓 means an open access publication.

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