7. Auction design objectives and baseline decisions

Summary

- Auction revenue attracts attention and maximising it can be a legitimate policy objective, but it should be subsidiary to improving economic efficiency because the effects of spectrum auctions on consumer benefits are typically much larger.
- Neither economic efficiency nor revenue-raising is served by high reserve prices that lead to unsold spectrum. The regulator should be confident that reserve prices are set below market value to encourage participation and price discovery in the auction.
- Other important baseline auction design questions concern demand linkages between bands favouring simultaneous over sequential awards, and balancing simplicity and flexibility in the design of the lot structure such as using 'generic' lots that are not frequency-specific.
- Transparency and the reputation of the regulator are aspects of market infrastructure, both of which strongly affect the regulator's design choices and the success of spectrum auctions. For example, they condition whether the environment is regarded as safe and secure by market participants, and the acceptability of a second-price rule (set as the highest losing bid) where winning bidders do not have visibility of the prices they are asked to pay and must trust the regulator on fair enforcement.
- The regulator's information policy can vary the degree of transparency before, during, and after the auction. There are pros and cons about how much to reveal, including trade-offs between facilitating straightforward bidding and deterring strategic bids.

Common mistakes in spectrum auctions include picking unwise objectives, placing too much weight on revenue-raising, and setting counterproductively high reserve prices that leave valuable spectrum unused. This chapter begins by emphasising some high-level challenges that complicate spectrum auctions, such as spectrum blocks or bands being complements, strategic bidding, effects on downstream markets, and uncertainty. The other topics in this chapter are highlighted in

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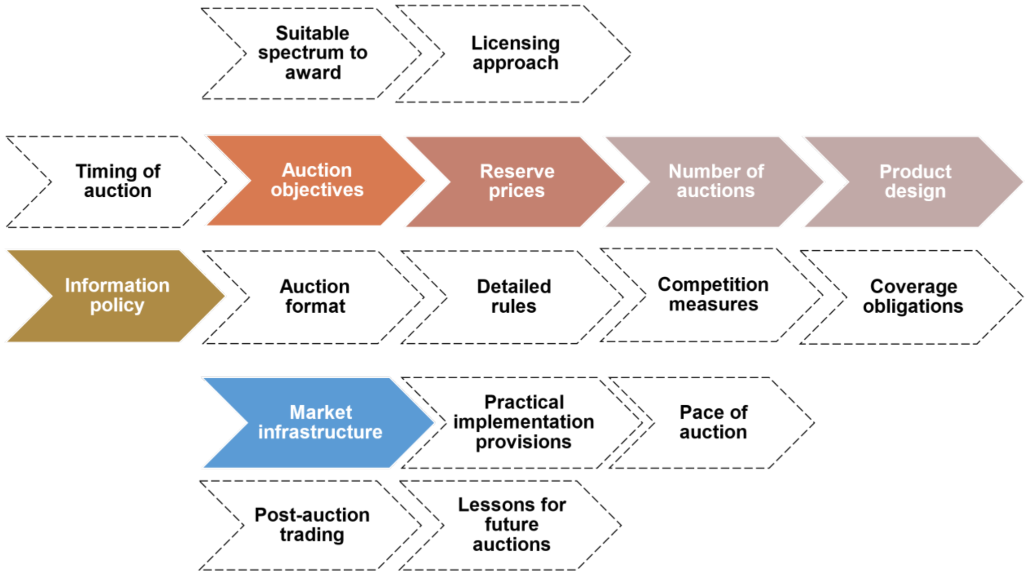
Figure 7.1. Auction decisions assessed in Chapter 7



Source: Author.

Figure 7.1. Since auctions are a means to an end, designing them and assessing their success depend on the objectives. The second section shows why economic efficiency should be given primacy over revenue. The third section explains how to avoid high reserve prices that can lead to inefficiently unsold spectrum. The last part of the chapter considers some specific baseline design choices for the regulator — the number of auctions showing why demand linkages favour simultaneous over several sequential awards, and the role of product design to specify the items that will be offered to bidders and the structure of lots. Finally, there is the analysis of the other two highlighted steps in Figure 7.1, information policy and market infrastructure, explaining the underpinning importance for the regulator of transparency and its reputation as market infrastructure.

7.1 Challenges of spectrum auctions

Designing an auction for any product raises its own issues. Spectrum auctions are challenging because the items being auctioned can be a combination of *substitutes* or *complements* for each other, with potential for a different mixture between bidders. Auctions for substitutes are generally less complex to design, and individual spectrum blocks, bands, or geographic areas can be substitutes for one another. Complements involve synergies between items that raise aggregation risks in bidding explored in the next chapter – for block sizes within a spectrum band, between bands, and between geographic areas. Mobile operators go into an auction with different pre-existing portfolios of spectrum and varying commercial strategies, which provide reasons why the spectrum in the auction can be seen as substitutes by one bidder and complements by another.[1]

Figure 7.2. Terminology for auction analysis

Auction efficiency	Allocating the spectrum in the auction to the highest-value bidders.
Output efficiency	Maximising the incremental gain in net social value in output markets, here downstream mobile markets.
Intrinsic value	The value to an operator from using the spectrum – the difference in expected profit with and without it, e.g. from additional, new or improved services, or from cost savings (without weakening the downstream competition process, and so excluding any strategic investment value).
Strategic investment value	The profit expected by an operator from foreclosing spectrum to rivals so as to weaken downstream competition.
Straightforward bids	Bidding according to intrinsic value.
Strategic bids	Deviations from straightforward bidding.

Source: Author.

Another challenge arises because mobile markets are oligopolistic, so that a small number of companies are generally bidding against each other in spectrum auctions. Therefore, bidders usually expect to be able to influence the auction outcome through their bid decisions, creating incentives for a range of different types of strategic bidding. A bidder may aim to improve its own outcome, such as obtaining lower prices for desired spectrum through demand reduction or coordinated market division. Or it may seek to worsen rivals' outcomes, such as by using 'price-driving' to increase their auction payments, or denying them key spectrum by acquiring it through 'strategic investment' (so as to weaken downstream competition).

It is useful to distinguish between *auction* efficiency and *output* efficiency (see Figure 7.2). Both build on the perspective about the size of the proverbial cake and conceptual underpinnings explained in Section 3.1. But they relate to the preferences of different agents. Auction efficiency maximises the cake in terms of bidders' values for spectrum, so it is achieved when licences are awarded to the highest-value bidders. It provides a useful conceptual benchmark when considering alternative auction design choices. But just as spectrum is an input not the output, auction efficiency is an intermediate objective, a means to the more important ends of promoting output efficiency. That relates to maximising social value in relation to preferences in the downstream (retail or output) markets where people obtain and consume their mobile services.[2]

The distinction between auction and output efficiency assists in structuring the discussion. This chapter and Chapter 8 are principally concerned with auction efficiency, namely achieving an efficient allocation of spectrum between the companies bidding, given their values. Chapter 9 focuses on output efficiency by considering the risks that bidders may engage in strategic investment to deny spectrum to rivals, which can lead the regulator to impose corrective competition measures in the auction, such as spectrum caps, in order to prevent harm to downstream competition and consumers. Broader social and public value from extending mobile coverage has already been considered in Section 5.3 – this is another influence on output efficiency. In other words, auction measures for downstream competition and for coverage extension seek to align auction efficiency with output efficiency, so that the auction winners will then deliver the greatest social and public value.

Another distinction is between *straightforward* and *strategic* bidding. Firms bidding for licences often do not think in terms of separating their spectrum valuations between intrinsic and strategic value, or correspondingly in their bid strategies between straightforward and strategic bidding. One source of value to an operator can be reducing the costs of providing mobile services (sometimes called 'technical value'). Another is providing more or better services ('commercial value'), including gains from attracting new retail subscribers from competitors. Taking actions to enhance profits and win customers from rivals is part of healthy competition. It is only detrimental if it adversely affects auction or output efficiency, such as by weakening the competitive process in the downstream market through strategic investment. Distinguishing in practice between reflecting and restricting competition can be difficult. For instance, a constant challenge in antitrust analysis is drawing the line between firms inflicting damage on competitors versus harm to the competitive process itself. Operators may not see it in these terms, focusing instead on ways to gain revenues and reduce costs, often without making a conscious choice between intrinsic-value or strategic bids. However, the distinction is important for regulators, both conceptually and for many of the practical decisions discussed in this and later chapters.

Operators invest significant effort in working out their spectrum valuations and bid strategies. Values are forward-looking, depending on expected changes in technology, patterns of consumer demand, and competition many years into the future. So another challenge for bidders and spectrum auction design is uncertainty. For example, an operator knowing its own private values is not as obvious as it might seem. Estimated values can vary greatly because valuation modelling is far from an exact science. In addition, bidders' values depend in several ways on what happens in the auction itself, notably on price discovery such as common value uncertainty, on other items acquired by the bidder whether substitutes or complements (addressed in Section 8.2), and on items acquired by rivals that affect downstream competition (covered in Chapter 9).

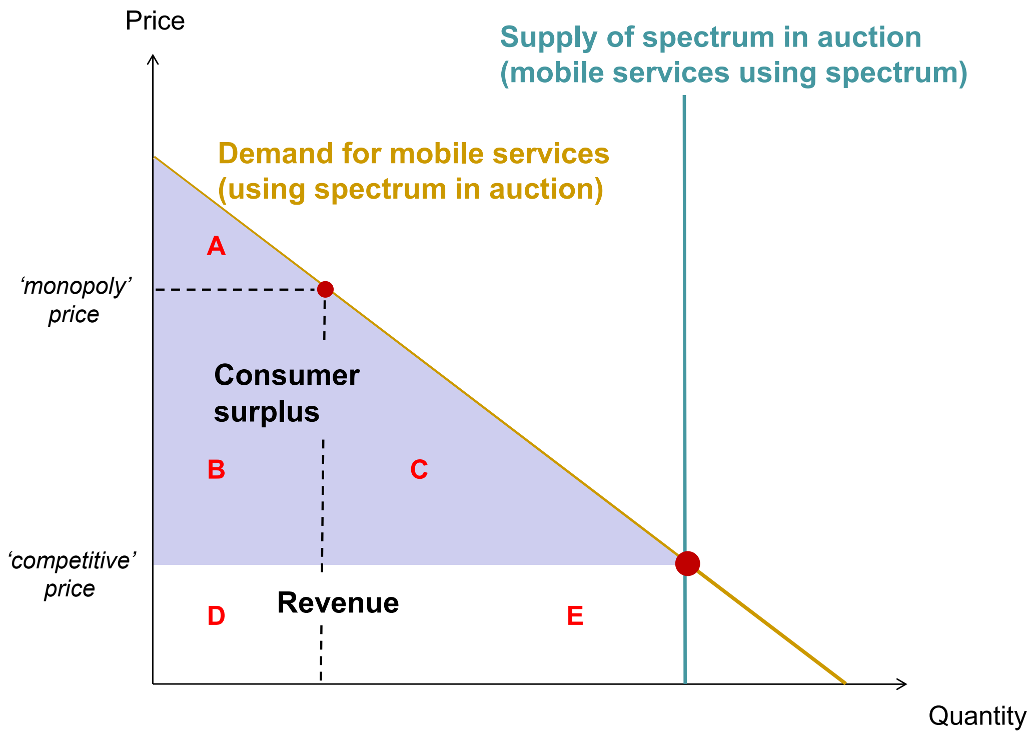
7.2 Objectives: why economic efficiency is more important than revenue

The revenues raised from auctions regularly attract the most publicity, and can be a legitimate policy objective. But enhancing the efficiency of the spectrum allocation is usually far more important in terms of benefits for consumers and social value.[3]

How auction revenues and consumer benefits are related

The relationship between auction revenue and economic efficiency has two key elements: first, the essential direction of causation is *from* expected downstream prices to the auction price, not the other way round; and second, there are trade-offs between maximising auction revenue and consumer benefits. Figure 7.3 gives a highly stylised illustration, which is not intended to be realistic or taken literally, but can show in a simple way these two high-level insights (whose kernel remains relevant alongside various complications in more realistic conditions that are explored in later sections and chapters, allowing for uncertainty, price discovery, substitutes and complements, etc.). The price is shown on the vertical axis and the quantity on the horizontal axis. The downward-sloping demand curve means that demand for spectrum and mobile services both increase at lower prices. The vertical supply line shows a fixed supply of spectrum in the auction. For ease of illustration, the diagram

Figure 7.3. Illustration of auction revenue and consumer benefits



Source: Author.

compresses two markets at different levels in the vertical chain: the input spectrum market (the auction) and the downstream output market where consumers buy retail mobile services.

To see how much mobile operators are willing to pay for spectrum in the auction and the gains to consumers, consider the available size of the cake and the slices obtained by consumers and operators. The total cake is represented by the sum of the rectangle and triangle in the downstream market (area A+B+C+D+E). Within this, the shaded triangle (area A+B+C) represents the consumer benefits at the 'competitive' price in the downstream market. If the demand curve is interpreted as the marginal willingness of consumers to pay, this area is the excess over the price paid ('consumer surplus'). The revenue obtained by operators is a uniform price multiplied by the quantity of mobile services supplied using the spectrum, given by the rectangle below the 'competitive' price line (area D+E). This revenue (net of costs) is what operators expect to earn in the downstream market using the spectrum, and so is their value for the spectrum in the auction.

There are many gross simplifications involved in this account, to be noted in a moment. But the first high-level point is that the essential direction of causation is that bidders' willingness to pay for spectrum in the auction, and hence the auction price, is derived from the prices and quantities they expect to sell using that spectrum in the downstream market. High or low auction payments do not change the downstream prices that mobile operators charge their retail customers (although caveats and potential exceptions are discussed later).

Next, the second high-level point of a trade-off between auction revenue and consumer benefits can be illustrated, again in a highly stylised way. To keep things as simple as possible, costs can be introduced by assuming that the mobile operators' marginal costs for each unit of output are equal to the competitive price line (and assuming no fixed costs). At that cost, operators earn no profit in the downstream market (costs equal revenues).[4] Now imagine that the regulator artificially restricts the amount of spectrum in the auction so that it is the dotted vertical line to the left in Figure 7.3, and additionally sells it only to a single operator. This creates an artificial spectrum scarcity, and accordingly the size of the cake is much smaller, now comprising only a fraction of the shaded triangle (area A+B), and excluding the smaller rectangle at the bottom (area D) which is the costs. If the spectrum is sold to only one operator, the distribution of slices of this smaller cake is also different. The downstream price is set higher by the monopoly operator at the monopoly price, so that the consumer benefits are only the small triangle sitting on top (area A). The large shaded rectangle left of the dotted line (area B) is the profit of the monopoly operator gaining the spectrum.

In this stylised set-up there can still be competition in the auction to win the spectrum, with firms in effect competing for a monopoly franchise, the right to be the monopolist in the downstream market.[5] If that competition is fierce, the revenue raised by the auction would be the entirety of the shaded rectangle within the dotted lines (area B). This would occur because each bidder is willing to pay up to that amount to become the downstream monopolist, and competition in the auction could lead the auction price to be bid up to that level. Thus, in this example the artificial scarcity of spectrum leads simultaneously to much *higher* auction revenue and much *lower* consumer benefits.[6]

Of course, there are many simplifying assumptions in this stylised analysis, in addition to abstracting for simplicity from uncertainty and dependencies of spectrum values on the auction. These include (but are not limited to):

- Uniform downstream prices: in practice, mobile tariffs are far from uniform. For example, contract or post-pay tariffs are typically two-part, with consumers paying a monthly subscription including a bundle of calls, texts, and a data allowance, plus out-of-bundle (or overage) charges if consumption exceeds the bundle. There is also a wide variety of contracts for different sizes of bundles at different prices which can vary between customers. In simple terms, non-uniform prices can allow operators to obtain a larger slice of the cake by capturing more of the consumer surplus. However, there is also potential to increase the size of the cake (with more realistic cost assumptions) through incentives to expand output, so that some consumers could benefit as well.
- A fixed relationship between the quantity of spectrum and downstream services: in practice, this relationship is far from fixed. Operators have substitute inputs to increase mobile capacity, such as more base stations (densification) or more spectrally efficient technology (e.g. replacing 4G services with 5G). Also, incentives for firms to invest and innovate can expand the size of the cake.
- Spectrum in the auction that changes downstream competitive conditions: of the assumptions highlighted here, this is the least unrealistic (although it is presented in an extreme way in the stylised narrative). It is generally the case that spectrum in high-stakes auctions can affect the competitive structure of the downstream market. Indeed, that is why a competition assessment is so important and the regulator often imposes measures to promote downstream competition, like setting spectrum caps or reserving spectrum for new entrants.

Hierarchy of objectives: economic efficiency over revenue

Given the potential conflict between revenue and consumer benefits, which should be given priority? The UK's 2000 auction raised an eye-watering amount of revenue and was dubbed the 'biggest auction ever' in a scholarly paper by the two eminent auction theorists who advised the regulator, Ken Binmore and Paul Klemperer.[7] The revenue of £22.5 billion was roughly 10 to 20 times larger than the pre-auction estimate (£1 to 3 billion). Yet even for this auction, there are estimates that the consumer gains were larger still.[8] The disparity between consumer gains and revenue is likely to be much bigger for later UK auctions. In the 2013 auction the revenue was £2.4 billion, and the regulator's estimate of consumer benefits is reported as £20 billion, almost ten times larger.[9] A similar kind of ratio also seems plausible for the 2018 auction, which raised revenues of £1.4 billion but enabled earlier deployment of the latest wave of mobile technology, 5G. Initially, 5G services were evolutionary (such as faster mobile broadband). But the functionality (including connected devices and increased responsiveness) also offered the potential for more revolutionary changes in personal and business communications through new 'killer apps'.[10] The precision of any estimates of consumer gain from auctions is doubtful, because they are derived by imposing a model and making various assumptions, and so are subject to significant error margins. Even so, these auctions support the broad view that consumer benefits are generally much larger than auction revenue.

Treating revenue as a subsidiary objective can be justified on economic efficiency grounds as a more efficient way to raise public funds than general taxation. The revenue generated by spectrum auctions can avoid creating a distortion of outputs, because of the first high-level point explained in the previous subsection – in the first instance, the direction of causation is that auction bids are determined by the expected future profit from outputs using the spectrum (instead of output decisions being determined by the price paid for spectrum in the auction). In contrast, taxation, the main alternative way for the government to raise funds, normally leads to both pricing and output distortions.[11]

In the UK's auctions, consumer gains from economic efficiency were prioritised over revenue-raising. The objectives for the 2000 auction run by the Radiocommunications Agency of the Department for Trade and Industry were, in effect, auction and output efficiency, with revenue as a secondary objective (as part of the 'full economic value to consumers, industry and the taxpayer').[12] Later auctions were run by Ofcom under legislation that did not include any duty or objective on revenue-raising, so that the objectives were related to improving auction and output efficiency, and excluded any concern about the revenue generated. The regulator's auction design decisions were justified only by reference to these efficiency objectives and not to revenue-raising, it made no revenue forecasts, and it did not consider options about trade-offs between revenue and efficiency.

This is different from some other regulators around the world who have revenue-raising as a policy objective, and sometimes specific revenue targets, as in India and the USA (such as the incentive auction outlined in Section 6.1). A range of blunt and subtle design choices can be used to affect auction revenue, which often (but not always) detract from economic efficiency. For example, the regulator may withhold spectrum to create artificial scarcity, restrict downstream competition, or set excessively high reserve prices (as in India). In addition there are detailed choices about matters such as the structure of lots, the auction format, and the information policy. For example, in Italy's 2018 auction of the 3.6–3.8 GHz band, the regulator decided to offer two lots of 80 MHz and two lots of 20 MHz, which limited allocation options and made bidders' choices closer to all or nothing. This lot structure seemed to increase revenue, by leading to bidding at high prices in the auction.[13]

There are potential risks for the regulator's design decisions related to caveats and exceptions to the argument that higher auction payments do not affect operators' subsequent decisions about either investment or consumer prices. This is a contested debate and some of the available evidence is mixed or inconclusive. On investment, one claim is that auction prices above opportunity cost expropriate companies' profits and so reduce their expectations of returns on future investment.[14] Another claim is that imperfect capital markets make operators more reliant to fund investments on internal financing, which is depleted by auction payments. However, even for the UK's very high revenue 2000 auction, the empirical evidence about 3G investment is conflicting.[15] For auctions after 2000, which yielded much lower revenue, the effects on investment seem less plausible. However, in a cross-country study there is some evidence of an adverse effect of higher revenues on subsequent investment.[16] If these empirical results are robust, the underlying causes could be deviations from best regulatory practice, such as design decisions leading to artificial spectrum scarcity or excessively high reserve prices.

Some commentators argue that auction payments represent a fixed or sunk cost for mobile operators which does not affect opportunity cost and so has no impact on downstream prices to consumers.[17] Others suggest that higher consumer prices can derive from behavioural effects amongst operators such as loss avoidance, or from reduced competition due to an elevated risk of collusion.[18] However, there is little empirical evidence that there are effects of auctions on mobile consumer prices.[19]

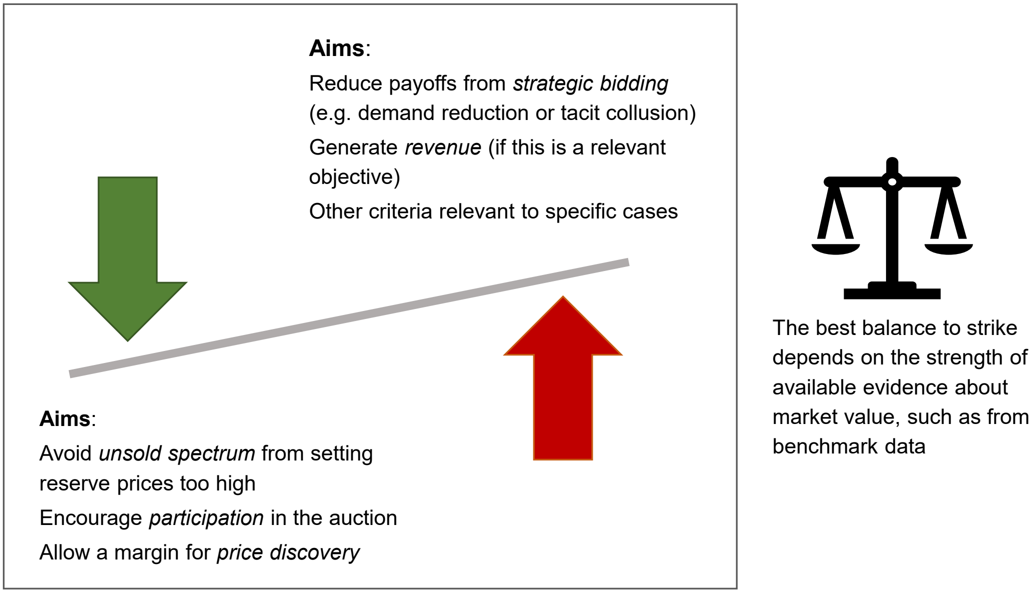
To the extent that the contested effects on investment or consumer prices are present, they represent a reduced risk when the key objective of (auction and output) efficiency is appropriately prioritised over revenue. In economic efficiency terms, there is an asymmetry – if high prices prevent or delay spectrum being put to productive use, then much greater risks come from auction prices that are too high than too low. This can arise from reserve prices being set too high, analysed next.

7.3 Reserve prices set below market value avoid unsold spectrum

The single most common mistake in spectrum auctions is setting the reserve price too high in an attempt to increase the revenue raised. There are many examples where high reserve prices led to unsold spectrum, including (but not limited to) auctions conducted in Australia, Bangladesh, the Czech Republic, Ghana, India, Italy, Jordan, Mozambique, the Netherlands, Norway, Portugal, Romania, Senegal, Slovenia, Spain, Switzerland, and Turkey. To pick one example, India was an early adopter of spectrum auctions from 1994. The regulator (the Department of Telecommunications) emphasised revenue as an objective, and there have been complaints about high reserve prices across successive auctions.[20] Spectrum was left unsold in six of the seven auctions held between 2010 and 2021, including a majority of the spectrum on offer failing to sell in several cases.[21] Perhaps as a consequence, there was less mobile spectrum in use in India in 2020 than comparator countries or regional averages – India used 310 MHz compared to Indonesia's 450 MHz, Brazil's 590 MHz, or the Asia-Pacific average of about 400 MHz.[22] Some regulators in Africa have similarly been criticised for failing to release enough spectrum and setting excessively high reserve prices (accompanied in some cases by poor planning and corruption).[23]

A higher reserve price can reduce participation by deterring potential bidders from entering the auction, or bidding for a spectrum band. In a competitive auction, the reserve price usually does not increase the revenues generated, because auction prices are set by competition between the bidders.

Figure 7.4. Framework of trade-offs when setting reserve prices



Source: Author.

One exception is where the reserve price is below the winner's value but exceeds the value of the highest losing bidder (which would otherwise set the price to be paid). However, since the regulator is normally uncertain about the bidders' valuations, it faces a clear risk of misjudging and inadvertently setting a reserve price that also deters high-value bidders to the extent of leaving spectrum unsold. Such an outcome is a good illustration of compound regulatory failure:

- Failing to achieve the desired revenue objective. Of course, no revenue at all is earned on unsold spectrum, so high reserve prices can backfire if set to raise revenue.
- Unintended consequences – preventing or delaying the unsold spectrum from being put into productive use to benefit consumers.

The UK regulator has avoided this regulatory failure, perhaps in part because, without a formal duty or objective relating to revenue-raising, it has not set reserve prices to increase revenue.

There is still a trade-off to be made, as Figure 7.4 shows. On the one hand, some considerations point towards lower reserve prices in order to avoid unsold spectrum, encourage participation, and promote price discovery. On the other hand, where there is a risk that the auction may not be competitive (which is an occupational hazard in spectrum auctions due to the usually small number of bidders), higher reserve prices can mitigate the incentives for operators to engage in some types of strategic bidding by reducing the payoff, such as making tacit collusion less profitable. In such circumstances, a price floor can affect the bidding and outcome with positive gains both for efficiency and revenue. Higher reserve prices can also help on other criteria in specific cases, e.g. to avoid contributing to an excessively slow auction as in Portugal in 2021 (see Section 11.2).[24]

From an economic efficiency perspective, it is desirable for the regulator to be confident that reserve prices are low enough to be below market value, allowing the auction to do its job of setting prices.[25] A floor on the level of reserve prices to set can be the opportunity costs from alternative uses of the spectrum.[26] This still leaves a wide range. The weights to accord to different considerations will depend on the circumstances, such as the risks that are most likely or worrisome, and on the objectives of the auction. The strength of the available evidence, such as from benchmarks, will also affect how to strike the best balance. Reserve prices can be set more or less conservatively relative to benchmarks – for example, lower if there is a lot of uncertainty about demand.

Applying the framework can lead to the regulator adopting a different approach to bands included within the same auction. For example, in the UK's 2013 auction, the reserve price for the 800 MHz band was set at £225 million per 10 MHz lot, closer to the estimate of market value than was Ofcom's standard practice. In this auction a specific additional consideration suggested higher reserve prices, namely the need to manage the trade-off between auction efficiency and the promotion of competition when reserving spectrum (see Section 10.1). The circumstances were very different for the 2.6 GHz unpaired spectrum in the same auction.[27] There was a great deal of uncertainty about the strength of operators' demand for this band, so the market value could have been very low. Accordingly, the reserve price was set especially low (only £0.1 million per 5 MHz lot), and the auction bidding resulted in very much higher final prices at more than £6 million per 5 MHz.[28]

Another example of disparity between reserve prices for bands in the same auction comes from the UK's 2021 auction which included two 700 MHz bands: higher-value paired spectrum (£100 million per 10 MHz lot), and lower-value spectrum for supplementary downlink (SDL) (£1 million per 5 MHz lot) used to carry traffic only in one direction from the base station to the consumer's device. Benchmarks for market value were available for 700 MHz paired, and the regulator set the reserve price near the bottom of the range, confident that it would be below market value. However, no useful benchmarks were available for the 700 MHz SDL band, and there was also substantial uncertainty at the time about demand – for example, this spectrum had gone unsold in a number of earlier auctions in other countries, such as Italy and Sweden. In the 2021 auction all spectrum in both bands was sold. The regulator was vindicated in setting a low reserve price for 700 MHz SDL, because it allowed the spectrum to sell even though it only attracted only a single bid at this price (with apparently no other bidder having a value above even this low price).[29]

The benchmarks for market value generally used to inform reserve prices come from earlier auctions, or from auction prices in other countries for the same or similar spectrum bands. There is a lot of 'noise' in this dataset, with large variation in prices reflecting an array of factors, some idiosyncratic to each continent, country, or auction. Econometric analysis is possible, and can be useful for drawing out implications on average. But the variation in the data makes it difficult to derive reliable estimates for specific bands in a particular country. The regulator can also undertake modelling of operators' expected spectrum valuations but only with a large error margin, given the sources of uncertainty in second-guessing firms' plans, revenues, or costs many years into the future. However the estimates of market value are derived, careful interpretation is required.

One approach to reduce noise in the data is deriving relative-value, instead of absolute-value, benchmarks. Absolute-value benchmarks are the auction prices in the benchmark countries. Conversions and adjustments are still required, such as for differences in currency, population, auction year, licence duration, or other provisions affecting prices (like coverage obligations). Relative-value benchmarks take the ratio of auction prices for two different bands in the benchmark country and apply it to market value of the comparison band in the home country – for example, UK-equivalent relative-value benchmarks for 700 MHz paired were derived to inform the reserve price for the 2021 auction by taking the ratio of auction prices of 700 MHz to 800 MHz in each benchmark country, such as Germany, and applying it to the market value of 800 MHz in the UK. The rationale for relative-value benchmarks is that they control for some of the country variation by extracting from the benchmark country only the ratio of prices (on the assumption that similar country-specific factors are present in both auction prices). This approach, of course, still requires ascertaining the market value of a home country comparison band, to which the ratio can be applied. It can be more informative than absolute-value benchmarks, and much more so if the differences between home and benchmark countries are large, such as situated on different continents, or developed versus developing countries. The absolute- and relative-value benchmarks can differ significantly. For example, the UK regulator placed more weight on relative-value benchmarks for 700 MHz from various European countries ranging between £96 and 359 million per 10 MHz, compared to absolute-value benchmarks from these countries of £19 to 475 million.[30] Like other methods to inform reserve prices, the regulator should recognise the uncertainty and the potential for a significant error margin.

Overall, the current limited 'science' of reserve prices is represented by the derivation of benchmarks, consideration of a framework of relevant considerations, and an analysis of their relative importance in the specific circumstances of a particular auction and spectrum band. Setting reserve prices is usually more of an 'art' based on the interpretation of the evidence and the degree of judgement involved, with the analysis often suggesting a wide range without a clear-cut or obvious answer. However, being clear about the objectives, the nature of the trade-off, and the degree of uncertainty in benchmark information (as in the analytical framework in Figure 7.4) can all assist the regulator to set a reserve price below market value and avoid unsold spectrum.

Setting reserve prices in practice is generally less closely based on the scholarly literature than other auction design decisions.[31] The choice of reserve prices has been studied rather less for circumstances that are more relevant to spectrum auctions (such as multi-unit with asymmetric bidders). So, there is scope for future academic research to provide greater practical guidance on reserve prices, perhaps including simulations to explore the trade-offs, such as the impact on strategic bidding incentives.

7.4 Choosing simultaneous or sequential awards depends on demand linkages

There are multiple items awarded in spectrum auctions, such as different blocks of spectrum, frequency bands, or geographic areas. Therefore, an initial question is whether to award them simultaneously in the same auction, or separated into sequential auctions. A simultaneous auction is especially relevant where different items are expected to be substitutes, allowing bidders to switch between them based on their relative prices; or where they are complements, so that bidders can realise synergies between items. Alternatively, bidders' demands could be independent, meaning that their values for one band are unaffected by whether or not they acquire the other. Independent demand does not imply a strong basis for a simultaneous auction, but there might still be pragmatic reasons such as economising on the time and cost of running separate awards.

A mix of these three rationales (substitutes, complements, and pragmatism) applied to the four high-stakes auctions in the UK:

- The 2000 auction involved only a single band of spectrum (2.1 GHz) which was organised into five national licences, two larger with more spectrum and three with smaller licences. Companies were permitted to bid for no more than one of these licences in any round. The licences were offered simultaneously, allowing substitution between larger and smaller licences.
- The two bands in the 2018 auction (2.3 GHz and 3.4–3.6 GHz) were both capacity spectrum. They were substitutable to some extent, although not very close substitutes as one was initially for 4G and the other for 5G services. Including them in the same simultaneous auction facilitated any switching between them, and also had a pragmatic rationale.
- The three bands offered simultaneously in the 2013 auction were a combination of substitutes (2.6 GHz paired and 2.6 GHz unpaired) and complements between spectrum principally for coverage (800 MHz) and for capacity (the 2.6 GHz bands).
- There was also potential for substitutability and complementarity among the three bands in the 2021 auction (700 MHz paired and SDL as possible substitutes; and 700 MHz and 3.6–3.8 GHz as possible complements). However, in this case the forces for interdependence of demand were much weaker than in 2013. Therefore, it was in part a pragmatic justification to offer them simultaneously in the same award, so as to bring the spectrum into use as soon as possible.[32]

The 2018 and 2021 auctions also provided an example of spectrum forming a wider band (3.4–3.8 GHz overall) that ended up being awarded sequentially, the 3.4–3.6 GHz band in 2018 and the 3.6–3.8 GHz band in 2021. It was not ideal to split this spectrum between auctions three years apart, because the bands were close substitutes for early 5G deployment. They were also potential complements through synergy value for large blocks that were considered especially desirable for 5G technology. In this case the timing of the spectrum becoming available determined the choice of sequential auctions – 3.4–3.6 GHz was available to be awarded sooner, whereas 3.6–3.8 GHz required band clearance to be justified and implemented. One option would have been to defer the award of the 3.4–3.6 GHz band until it could be conducted simultaneously with the 3.6–3.8 GHz spectrum. But this would have delayed operators' access to spectrum for 5G. Therefore, even if it led to later challenges because of the 'fragmentation' of the wider 3.4–3.8 GHz band into non-contiguous blocks (see Section 11.3), the sequential approach allowed earlier 5G services to be offered to consumers in 2019.

7.5 Deciding the items offered for sale and the structure of auction lots

A key aspect of product design is how the spectrum in the auction is subdivided or organised into the items or lots on which operators can make their bids. For the UK's 2000 auction, there was a simple approach of five pre-packaged national licences. British operators are usually interested in spectrum allowing nationwide deployment, and all the high-stakes auctions up to 2021 have been for UK-wide licences. But there has been a move over time to specifying more *granular* lots of smaller spectrum amounts. As the spectrum portfolios of the mobile operators grew over time, there was greater diversity in their relative spectrum demands. For example, in 2018 Ofcom organised the 3.4–3.6 GHz band into 30 lots of 5 MHz each. Granular lots also offered the prospect of encouraging participation by smaller operators (as in the 2013 and 2018 auctions).

The choice of pre-packaged or more granular lots provides a specific example of a trade-off that applies more generally in auction design between *simplicity* and *flexibility*. The pre-packaged lots for the 2000 auction simplified the bidding process, but limited the flexibility for bidders. There were two different lot or licence sizes (20 MHz and 30 MHz), but in any given round a firm was not able to bid for less spectrum than in the smaller lot size, nor more than in the larger. By contrast, in the 2018 auction, operators could bid in the 3.4–3.6 GHz lot category in each round for a small amount of spectrum or a very large amount. They did so, with observed bids for many different amounts up to and including 30 lots (150 MHz, the entire band). There is a flip-side to the greater flexibility provided by the wide range of options, namely increased complexity and more opportunity for strategic bidding by operators. Flexibility can therefore be taken too far. An example of too much granularity would be 'postage stamp-sized' lots for spectrum amounts or geographic areas that are too small to be valuable on their own, creating substantial synergies and aggregation risk (see Section 8.2).[33]

In the case of 3.4–3.6 GHz spectrum, the lot size was chosen because 5G technology allowed deployment in multiples of 5 MHz. The 30 blocks of 5 MHz were not identical, because some bidders had preferences for frequencies at the top of the band, for example. In such a situation it was possible to offer the band in 30 categories with a single frequency-specific lot in each. But instead they were standardised or conflated into 'generic' lots within the same category, and treated as if they were homogeneous for that stage of the auction. This suppressed any distinctions bidders might have wished to make between items within the category.[34] But the advantage of conflation is that it enhances market thickness (more bids per category), substitution, price discovery, and speed of the auction, which all contribute to its success.

This example illustrates a common product design choice where conflation is used to split the auction into two stages. Initially, in a 'principal' or main bidding stage, there are bids for a single category of generic lots for a band to determine the amount of spectrum won by each bidder. It is then followed by an 'assignment' stage with bids for preferred frequencies within the band, such as the top, middle, or bottom. This approach also guarantees that each winning bidder obtains a set of contiguous frequencies in the award spectrum, which is usually more efficient because of the way that mobile technology is optimised. In effect, there is conflation in the principal stage followed by deconflation in the assignment stage.[35] The final price paid by a winning bidder is the sum of the (conflated) price in the principal stage and the (deconflated) price in the assignment stage. Generic lots are widely used around the world (and in the UK since 2007) because they generally provide a desirable balance between market thickness, contiguous assignments to operators, and bidders' expression of their preferences.

However, their effectiveness depends on decisions about lot categories, which influence the distribution of activity between different parts of the auction, and when bidders can express their preferences. If an operator has large value differences between frequencies included as generic lots in the same category, its bid strategy during the principal stage is more complicated. It has to manage the risk that it may fail in the subsequent assignment stage to win its favoured frequencies and could end up with its lower-value frequencies. On the other hand, separate lot categories could lead to a risk of winning fragmented (non-contiguous) spectrum, reducing value. The choice of lot categories as generic, frequency-specific, or a combination of the two is, therefore, one of many trade-offs and judgement calls that the regulator needs to make.[36] Older spectrum auctions tended to use an alternative product design of frequency-specific lots, and some current ones still do so. This approach can be much slower and result in wider price dispersion for similar spectrum. An example of a half-way house is Portugal's 2021 auction. The lots were 'abstract' (not frequency-specific) ensuring contiguous assignments, but each lot still attracted separate bids without conflation. The separate bids contributed to the extremely slow pace of this auction – generic lots could have substantially reduced the auction's duration.

Use of UK-wide licences has made the geographic dimension in Britain relatively straightforward. Some countries (such as Australia, Canada, India, and the USA) use more granular geographic lots due to sub-national demand by local or regional operators. Or there can be a mix of national and regional areas, as in Brazil's 5G auction in 2021. Depending on circumstances, Canada applies one of five tiers for the geographic product design: tier 1 is the whole country; tier 2 splits it into 14 large service areas; tier 3 into 59 regions; tier 4 into 172 local areas; and tier 5 is the most granular with 654 areas.[37] For example, Canada's 2021 auction for the 3.5 GHz band used a product design of tier 4 areas with generic lots in each (up to 20 lots of 10 MHz).[38]

7.6 Regulatory reputation as key market infrastructure for success

One of the critical elements in any spectrum auction is the quality of institutions running it. In particular, the trustworthiness of, and market confidence in, the regulator can affect whether and how the auction can be successful. The regulator's reputation can assist or undermine it being seen by market participants as operating the auction with integrity, honesty, and fairness. A related factor is the transparency that the regulator provides before, during, and after bidding.

The country and cultural context for auctions is important for the non-physical market infrastructure of the regulator's reputation. In some countries with weaker institutions or low levels of trust in public agencies, the regulator can struggle to develop sufficient reputation to hold auctions that are regarded as safe and secure by market participants. Being seen as corrupt, or lacking competence, trustworthiness, rule-keeping, or professionalism can all change whether an auction can realistically be used to allocate spectrum. The regulator's reputation can also affect the way in which any auction is operationally run, such as requiring simpler rules, additional independent verification, or specific procedures such as safeguards for handling large sums of money.

Reputation and the trust of market participants can also limit the choice of auction design. For example, final prices in the Combinatorial Clock Auction (CCA) format are set by the highest losing bids, a second-price rule. In economic theory this rule has attractive properties of encouraging straightforward bidding, because operators shading their bids below their full value only reduce their chances of winning without affecting prices. However, running a CCA requires greater trust from auction participants, because a winning bidder does not have transparency about the derivation of the price it is asked to pay. The price is set by bids made by other bidders, not the winning bidder itself. The auctioneer sees both the winning and highest losing bids, and there is scope for it to exploit this information asymmetry, such as by charging the winner a price well above the highest losing bid. This behaviour has been modelled in theory and observed in practice in private-sector applications (e.g. in auctions of stamps).[39] In practice, there are second-price auctions, such as used by eBay, but potential concern about the trustworthiness of the auctioneer to stick to the rules is one reason this pricing rule is less commonly observed.

These problems can be mitigated if institutions assign importance to their own reputation. A regulator running a series of auctions should appreciate the (potentially irreversible) reputational damage that could be caused by failing to follow its own rules. In liberal democratic countries with closer scrutiny of public agencies and greater degrees of transparency, there are increased chances of misbehaviour being identified and revealed. To enhance trustworthiness, spectrum auctions are often run by independent regulators, at arm's length from politically controlled ministries, and with their own statutory duties and access to funding. These institutions can prioritise trustworthiness and transparency as important mechanisms for showing that they are accountable, especially given their lack of direct democratic legitimacy (see Section 4.2). Nevertheless the issue of trust remains highly relevant even for long-established regulators. For example, it was a reason for the USA's incentive auction in 2016–17 run by the FCC not to have a second-price rule when trying to encourage participation in the reverse auction by local TV stations inexperienced in such processes: 'Even if the computations could be performed perfectly accurately, many bidders in the auction would likely be unconvinced that the government could be trusted . . .'.[40]

Regulators who have adopted auctions with a second-price rule have generally put in place multiple levels of verification. For example, in the UK's 2013 auction, the prices were determined by an electronic auction system that had previously been audited by an external consultancy. They were also checked by independent calculations, and verified as being correct by another external consultancy.[41] In addition, all the losing bids were published after the auction, along with software to allow bidders to satisfy themselves that the rules had been followed.[42] Such mechanisms can enhance perceptions of procedural fairness and build trustworthiness, as well as being inherently valuable.

Turning to the issue of transparency, different approaches are taken by regulators. The information policy encompasses the regulator's choices of which information is made publicly available, or only to applicants or bidders before, during, and after the auction. Before the auction, many regulators seek to provide as much useful public information as possible. This could be via a detailed information memorandum, set in the context of a longer-term roadmap for the evolution of spectrum usage. It reduces uncertainty for potential bidders and their financial backers, assists them to develop their spectrum valuations, and signals the regulator's professionalism and reliability.

During the auction, for public information it is common practice to publish daily updates and the winning outcome at the end. Greater information is provided to bidders. The extent of transparency to bidders can strongly affect the trade-off in a set of auction design rules between firms' incentives for straightforward or strategic bidding. For example, during the UK's 2018 and 2021 auctions, the regulator limited the feedback provided to bidders to just the approximate level of aggregated demand in a range (instead of exact demand). This information policy choice sought to strike a balance between giving meaningful information to assist bidders to make more informed intrinsic-value bids, and restricting information that could facilitate strategic bidding given the auction format (covered in more detail in Chapter 8).

After the auction, regulators in the UK and some other countries have published all the winning and losing bids. Elsewhere, restricted publication is more typical, in some cases only revealing the winners and the prices paid. Post-auction transparency has both advantages and disadvantages. As we have seen, for an auction involving a second-price rule, it allows bidders to verify that the auction was run appropriately according to the rules. However, the UK regulator also published losing bids for those auctions with a pay-as-bid pricing rule, where this specific verification issue did not arise. In such cases, greater transparency can perform a different role, by building and maintaining an overall reputation for trustworthiness. Publication could also reduce bidders' incentives for strategic bidding, since their bids would become publicly known after the event. The downsides to post-auction transparency include risks of deterring straightforward bids if a bidder fears publication will reveal information that it regards as confidential, or adversely affecting commercial interactions after the auction or the bidding in future auctions.[43] In the UK's 2021 auction, for example, Ofcom departed from its usual policy of bid publication for the assignment stage of the 3.6–3.8 GHz band. Post-auction trading was especially important in that particular case for defragmentation (see Section 11.3), and the regulator was concerned that publication of all the bids could adversely affect it.[44]

Conclusions

A number of high-level challenges complicate spectrum auctions, such as spectrum lots being complements, incentives for firms to engage in strategic bidding, effects on downstream markets, and uncertainty. Generally speaking, revenue-raising should be a secondary spectrum auction objective compared to economic efficiency. The risk of setting excessively high reserve prices leading to unsold spectrum, a common mistake, can be mitigated by applying a tailored analytical framework to balance the relevant considerations and take account of the degree of uncertainty about market value. Demand linkages between spectrum lots in the auction favour a simultaneous auction over a number of sequential awards. There are advantages when deciding the structure of lots to use categories of generic lots so as to improve the speed and efficiency of the auction. Key market infrastructure includes the reputation of the regulator and the trust of market participants. The regulator's attributes can limit or broaden realistic auction design options, such as the feasibility of using a second-price rule. The information policy can also affect regulatory reputation, but there is a trade-off to be made because greater transparency has both advantages and disadvantages. This provides an example of the many trade-offs the regulator needs to navigate when designing spectrum auctions.

Notes

1 An indication of the resulting complexity from complements is that Milgrom (2000) shows in such circumstances there is no market-clearing price. The UK's 2013 auction provides a practical example of bids including synergies that did not allow the market to be cleared by uniform prices (which would have resulted in either excess demand or excess supply). The CCA design for that auction included non-linear prices, meaning that the marginal and average prices could differ for different amounts of the same spectrum and between bidders. It was the non-linear prices that allowed the market to clear.

2 Jehiel and Moldovanu (2003) call auction efficiency 'value maximization' and refer to output efficiency as 'allocative efficiency'.

3 Hazlett, Muňoz, and Avanzini (2012).

4 Where costs include the minimum required return on investment, reflecting the risk-adjusted cost of capital, 'no profit' means no excess profit but sufficient to reward investment.

5 The set-up is, however, quite different from so-called Demsetz franchise auctions to *protect* consumers of utility services, replacing regulation with competition for the market through an auction with bids to offer the *lowest* consumer prices. Williamson later argued this was a flawed approach due to uncertainty reintroducing the need for regulation. In contrast, the maximum auction revenue scenario here is *exposing* consumers to unregulated monopoly consumer prices by competition for the market through an auction with bids to offer the *highest* financial payments to the government. The preferred efficiency-based policy route is to protect consumers through promoting downstream competition *in* the market, not *for* the market. For a summary of the Demsetz-Williamson debate, see Masten (2010, pp.7–8).

6 Jehiel and Moldovanu (2003) discuss trade-offs between auction revenue and downstream competition. Milgrom (2000, p.269) notes that 'Particularly when the number of bidders is small,

the goals of efficiency and revenue can come into substantial conflict', and provides a formal analysis of an example.

7 Binmore and Klemperer (2002).

8 A simulation suggests consumer surplus gains that were 15 per cent larger than auction revenue – see Hazlett and Muňoz (2009a, p.433).

9 National Audit Office (2014). However, the detail behind Ofcom's estimate for the 2013 auction is not in the public domain.

10 For example, see 5G Comparison Site 'What is 5G?', https://5g.co.uk/guides/what-is-5g/ and Ofcom 'What is 5G?', https://perma.cc/8D3A-3Z9V.

11 Morris (2005).

12 Binmore and Klemperer (2002, p.C79).

13 Kuś and Massaro (2022).

14 GSMA (2017).

15 The cross-country empirical analysis by Kuroda and del Pilar Baquero Forero (2017) finds a negative impact of spectrum auctions on 3G penetration. In contrast, some other empirical analyses find no impact, namely Park, Lee, and Choi (2011), and Zaber and Sirbu (2012).

16 GSMA (2019).

17 For example, see Kwerel (2000).

18 Buchheit and Feltovich (2011), and Offerman and Potters (2006).

19 GSMA (2019) claims to identify some evidence that higher spectrum fees may have driven higher consumer prices in developing countries, although the results are not robust to different analytical approaches, and the evidence is inconclusive for developed countries. There is no effect of spectrum fees on consumer prices in Park, Lee, and Choi (2011). Similarly, a cross-country empirical analysis by Cambini and Garelli (2017) finds no impact of spectrum fees (or spectrum availability) on mobile revenues after controlling for endogeneity (that is, auction prices being determined by expected downstream revenues).

20 For example, reserve prices in India have on average been amongst the highest compared to other countries – see Figure 5 in GSMA (2017). For detailed critiques of the Indian regulator's methods to derive reserve prices, see Prasad and Kathuria (2017), and Kathuria et al. (2019, section 4).

21 For India's regional structure of licences, different methods can be used to estimate the proportion of spectrum unsold (e.g. number of lots, MHz amount, or population weighted). The minister is reported as claiming 40 per cent of spectrum unsold in the 2021 auction (see Capacity Media 'India's $11 billion spectrum auction closes', https://perma.cc/QMY6-GH76), but another estimate suggests 63% (see Wikipedia 'Indian Telecom Spectrum Auction', https://perma.cc/GA36-QAGZ). For proportions of unsold spectrum in auctions between 2010 and 2016, with a majority shown as unsold in 2012, 2013, and 2016, see Kathuria et al. (2019, figure 3.2).

[22] GSMA (2021a, figure 5).

[23] Lewis (2018), GSMA (2020), and Steve Song, 'The Failure of Spectrum Auctions in Africa', https://perma.cc/E385-PYYG.

[24] Although it has been rare in practice, a further possible consideration is to avoid speculative participation – see EU (2021, p.29).

[25] Market value is the market-clearing price in a well-functioning, competitive market. It can also be described as the marginal opportunity cost of the spectrum, reflecting the intrinsic value of the highest losing bidder. Spectrum can be sold at a reserve price above market value, due to the winning bidder's higher value than losing bidders. But this would eliminate participation by other bidders and price discovery which can enhance fairness and efficiency (e.g. if there are sources of common value).

[26] Costs of band clearance or spectrum management are sometimes used as a floor on reserve prices. Although this approach is pragmatic and not usually contentious, the efficiency arguments depend on whether the clearance issue is forward-looking. If clearance costs have already been incurred (or the commitment to incur them has been made), they are not strictly relevant for economic efficiency. Most spectrum management costs are fixed or common, whereas efficiency for a price floor relates to incremental costs.

[27] With unpaired spectrum using Time-Division Duplexing (TDD) technology, the carriers for the uplink from the mobile handset to the base station and from the base station to the handset are separated by time in the same frequency. With paired spectrum using Frequency-Division Duplexing (FDD), carriers for the uplink and downlink are in separate frequencies.

[28] In the CCA format used for the 2013 auction, the final prices were set for packages of spectrum and not for individual bands. There is no uniquely correct way to derive band-specific prices. The figure of more than £6 million per 5 MHz reflects one approach, namely estimating the linear prices that were closest to market-clearing prices — see Figure B1.7.

[29] This view assumes it would not have been better to refrain from selling the SDL spectrum in 2021 and instead wait to make it available in later years, or for different technologies or uses.

[30] Ofcom (2018b, figure 7.5).

[31] For analysis of optimal reserve prices, see McAfee and McMillan (1987), and Milgrom (2004, chapter 6).

[32] Ofcom (2020a, paragraph 2.27). In the event, there was no substitution between bands in the 2021 auction.

[33] Milgrom (2004, p.297).

[34] Milgrom (2011).

[35] Levin and Milgrom (2010).

[36] It is feasible to set up the auction so that the bids determine some aspects of the product design endogenously – see Ausubel and Baranov (2014). There have been three attempts in the UK, with mixed success. First, bidding in the 2006 DECT guard band auction determined the

number of licensees at 12 by allowing each bidder to make different bids depending on the total number of licensees between 7 and 12 (given that coordination with other licensees might be needed to use the spectrum). Second, in 2008 the regulator proposed to allow auction bids to determine how much 2.6 GHz spectrum would be paired (for 4G) and unpaired (for other technologies such as WiMAX), although this auction was never held – see Ofcom (2008a). Third, when 2.6 GHz was ultimately awarded in 2013, auction bidding determined a portion of the paired spectrum as standard power instead of low power, which was one of the least successful complications in the 2013 auction design (see Annex A3).

37 See Industry Canada 'Service areas for competitive licensing', https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/h_sf01627.html#tierMap.

38 See Industry Canada '3500 MHz auction – Process and results', https://www.canada.ca/en/innovation-science-economic-development/news/2021/07/3500-mhz-auction--process-and-results.html.

39 Rothkopf and Harstad (1995), and Lucking-Reiley (2000). Akbarpour and Li (2020, p.427) define an auction protocol as 'credible if running the mechanism is incentive-compatible for the auctioneer, that is, if the auctioneer prefers playing by the book to any safe deviation'. First-price sealed-bid auctions and ascending auctions like the SMRA format are credible in this sense, but the second-price sealed-bid stage (supplementary bids round) in the CCA format is not.

40 Milgrom (2019, p.393).

41 See Smith Institute letters to Ofcom Auction Team, 14 and 27 February 2013, https://perma.cc/T9HE-KSWL.

42 See Ofcom '800 MHz & 2.6 GHz Combined Award: Details of Bids Made in the Auction', Zip file, https://webarchive.nationalarchives.gov.uk/ukgwa/20220104120035mp_/http://static.ofcom.org.uk/static/spectrum/800_2.6_auction_bid_data_files.zip.

43 Rothkopf, Teisberg and Kahn (1990).

44 Ofcom (2020a, paragraphs 6.87 and 6.123–6.126).

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Note: means an open access publication.

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