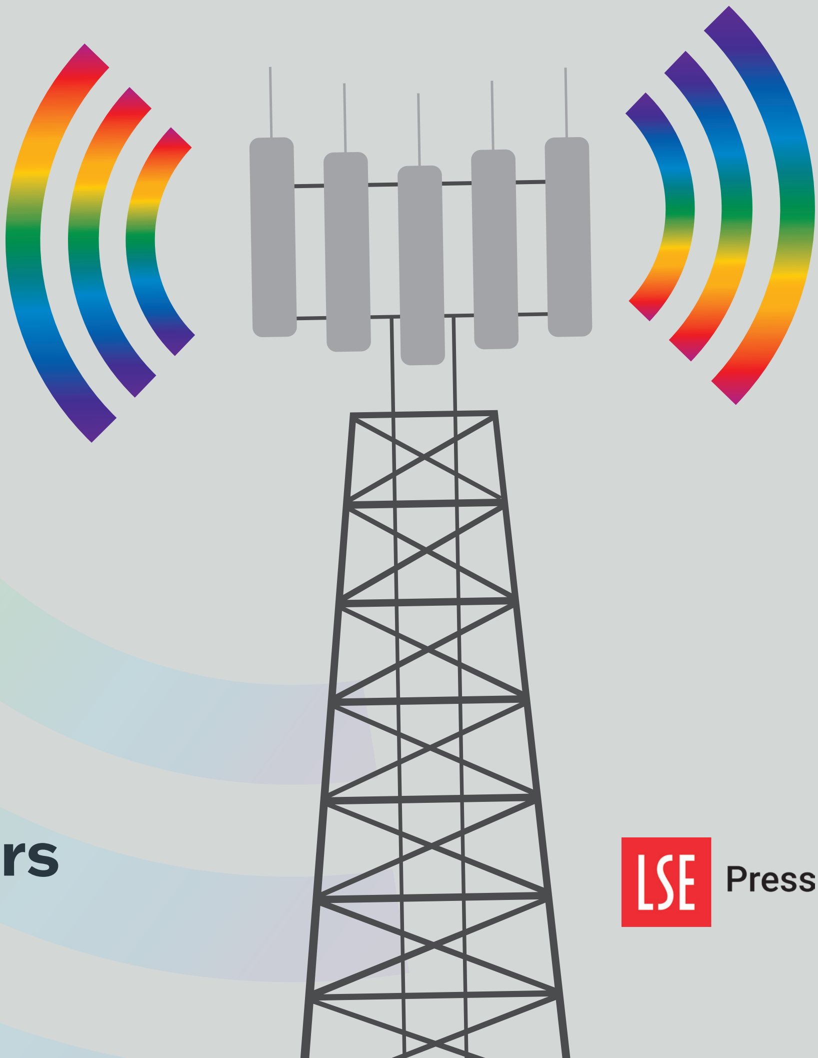
SPECTRUM AUCTIONS

Designing markets to benefit the public, industry and the economy



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Published by
LSE Press
10 Portugal Street
London WC2A 2HD
press.lse.ac.uk

First published 2023

Cover design by Diana Jarvis

Print and digital versions typeset by Siliconchips Services Ltd.

ISBN (Paperback): 978-1-911712-02-2
ISBN (PDF): 978-1-911712-03-9
ISBN (EPUB): 978-1-911712-04-6
ISBN (Mobi): 978-1-911712-05-3

DOI: https://doi.org/10.31389/lsepress.spa

The full text of this book has been peer-reviewed to ensure high academic standards.
For our full publishing ethics policies, see https://press.lse.ac.uk

Suggested citation:
Myers, Geoffrey (2023) *Spectrum Auctions: Designing markets to benefit the public, industry and the economy,* London: LSE Press. https://doi.org/10.31389/lsepress.spa. License: CC BY-NC-ND 4.0

To read the free, open access version of this book online, visit https://doi.org/10.31389/lsepress.spa or scan this QR code with your mobile device:

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Preface

I started my career in public agencies as a competition and regulatory economist, only later being drawn into the fascinating world of the theory and practice of market design through working on policy for management of the airwaves, namely radio spectrum. Over many years, I was a practitioner at the heart of work by Ofcom, the UK's communications regulator, to design and run spectrum auctions. My role was overseeing all aspects of economic analysis integral to the multidisciplinary approach, alongside professionals from other skill groups such as policy, engineering, legal, and information security. In this book I distil my experiences and learnings in policy development, decision-making processes, and implementation for wider application to countries using auctions and for aspects of public policy more generally (such as the role of experts).

While not shying away from the many nuances and complexities, the book is written to be accessible and of interest to a range of audiences including:

- those without prior knowledge who are interested in learning about spectrum auctions and broader themes of designing markets in the public interest, including general readers, students, and scholars; and
- more advanced technical readers interested in improving their in-depth understanding, including those involved in spectrum auctions around the world, such as regulators and other public bodies, companies who are current or potential bidders, and auction advisers.

The analysis for these diverse audiences reflects my perspective from working at Ofcom, and also teaching regulation and public policy at the London School of Economics and Political Science. Just as I have always operated in a multidisciplinary context, this book draws on insights from a range of scholarly fields in economics and other social sciences, including market design, industrial organisation, public and behavioural economics, regulation, and public management. Practical policymaking and implementation require marrying the expert's 'rational-comprehensive' technical analysis with the public manager's decision-making approach, which encompasses additional considerations and often involves 'incrementalism' from the status quo.

My method is theory-inspired practice, based on close experience of UK spectrum auctions, to draw out wider themes and frameworks relevant for structured public policy judgement. This broad perspective is not only due to the interplay between different social science disciplines, but also the end-to-end scope of the policy process. This reflects one of the great pleasures of working on spectrum auctions end to end, from 'soup to nuts', from making the spectrum available to be awarded, developing the policy to award it, navigating governance processes, through to practical implementation in the auction room, and post-auction analysis.

My approach also reflects working and life experiences which have taught me the virtues of:

- balancing rigour and inclusiveness of thought, because 'it is the people not like us that make us grow';[1]
- recognising that each discipline and every model have both strengths and limitations;[2] and
- marrying confidence in making a valuable contribution with humility that you do not know it all.[3]

Notes

1 Sacks (2021, p.358) and Jonathan Sacks 'How we can face the future without fear, together', TED talk, 26 July 2017 (at 4 minutes 54 seconds), https://www.youtube.com/watch?v=AMVgX8cXsHA.

2 'It's a model, not *the* model' – number 2 in the 'Ten Commandments for Economists' by Rodrik (2015).

3 'Some forty years of experience in my field as a scholar and as a teacher have given me great confidence mixed with greater humility' – Sarton (1959, preface).

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Acknowledgements

The book draws heavily on my experiences over many fruitful years at Ofcom. I have learned more than I can say from former Ofcom colleagues, and scholars with expertise in both theory and practice such as Peter Cramton, Paul Klemperer, and Paul Milgrom.

I am exceedingly grateful for helpful comments received from Paolo Belardinelli, Martin Cave, Yuelan Chen, Patrick Dunleavy, Eileen Emmanuel, Andy Hudson, Evan Kwerel, Paul Milgrom, Carlos Soto, Johanna Thoma, and anonymous reviewers. Simon Bastow prompted me to write this book, and Martin Lodge has been a source of great wisdom and encouragement. All remaining errors are my own.

About the author

Geoffrey Myers is Visiting Professor in Practice at the London School of Economics and Political Science. He previously worked in the public sector for regulatory agencies, including at Ofcom (the UK's regulator for telecommunications, broadcasting, post, and spectrum) for 25 years as Director of Competition Economics, and at the UK's Office of Fair Trading and the Jamaican Office of Utilities Regulation.

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Glossary

ACCC: Australian Competition and Consumer Commission.

ACMA: Australian Communications and Media Authority.

Activity rules: The restrictions that can be placed on bids to encourage **straightforward bidding**, such as not permitting companies to increase their demand as prices rise during the bidding rounds in an auction.

Aggregation (or exposure) risk: Where two different items in the auction are **complements** for an operator, it obtains a **synergy value** over and above its stand-alone values for each item, if it acquires both. However, placing individual bids for the items above their stand-alone values exposes the firm to making a loss, unless it is successful in winning both items.

Allocative efficiency: Maximising social value through the allocation of scarce resources (such as spectrum) to those users who will best deploy them.

Assignment stage: The part of the auction that determines the specific frequencies to be assigned to each winning bidder of **generic lots** in the **principal stage**.

Auction: A market mechanism used by an auctioneer to sell (or buy) items, where the outcome is determined by eliciting information through bids from competing buyers (or sellers) about their willingness to pay (or sell).

Auction efficiency: Allocating the lots in the auction to the highest-value bidders.

Auction theory: A branch of **market design** applying **game theory** that practitioners draw on when designing real-world auctions because it analyses bidders' incentives in response to different auction designs and can characterise the potential resulting outcomes in terms of **economic efficiency**, revenue, and bidder profits.

Band: A specified range of frequencies.

Bid shading: A company lowering its bid amount below its **intrinsic value** in order to reduce the price paid if it wins.

Capacity spectrum: Higher-frequency spectrum bands that are especially suitable for providing additional network capacity, because radio signals generally have more data-carrying capability, the higher the frequency.

CCA: Combinatorial Clock Auction, an auction format with **package bidding** in two stages: first, a **clock auction**; then a single round of sealed supplementary bids when each bidder can make mutually exclusive bids on as many different packages as it wants, but at most only one of these bids can win, and payments by the winning bidders are set according to a **second-price** rule.

Clock auction: An auction format where the auctioneer specifies the prices for each lot category, and bidders place bids for the quantities they want at those prices (and despite the name, there is no fixed time limit).

CMA: Competition and Markets Authority (the UK competition authority).

Commercial value: An operator's value of spectrum that is derived from being able to provide additional, new, or improved services.

Complements: Items for which the whole is worth more than the sum of the parts, yielding **synergy value** so that acquiring the first item increases the willingness to pay for the second.

Contiguous spectrum: Adjoining spectrum frequencies, which can usually be deployed more efficiently because of the way wireless technology is optimised.

Core: The set of outcomes that involve no coalitions preferring an alternative. The core is used in the second-price rule of the **CCA** and assignment stages, so that no losing bidder (as expressed through its bids) was willing to pay more than the auction price for spectrum won by others.

Coverage spectrum: Lower-frequency spectrum bands that are especially suitable for providing wide area network coverage, because radio signals generally travel further, the lower the frequency.

Densification: Augmenting the capacity of a mobile network by increasing the number of base stations or cells in a given geographic area.

Downstream: A later point in the supply chain – for example, mobile spectrum is an **upstream** input used in the downstream supply of wholesale mobile services to **MVNOs** and retail services to consumers such as mobile internet access, texts, and telephone calls.

Dutch auction: A multiple-round auction with descending prices until bidders make bids offering to buy the items that are being awarded.

Dynamic efficiency: Maximising the investment and innovation that is valuable for **social welfare**.

Economic efficiency: Maximising **allocative**, **productive**, and **dynamic** efficiency.

Eligibility: The metric often used in **activity rules**, such as the maximum number of lots the bidder is permitted to bid for in a specified round in a single-band auction, or the number of eligibility points in a multi-band auction.

English auction: An open, ascending multiple-round auction with **standing high bids**, such as used in auctions of fine art.

Exclusive licence: A licensee having the sole right to make radio transmissions in the specified frequencies and locations (usually subject to technical conditions that manage the risks of interference with neighbouring users).

Externality: A spillover cost or benefit to others caused by a decision-maker who does not have an incentive to take that effect into account (e.g. the radio transmissions of one spectrum user causing harmful interference to neighbouring spectrum users).

FCC: Federal Communications Commission, the regulator in the USA for communications services including spectrum management.

First price: The rule to set the payment by an auction winner using its winning bid (sometimes this term only applies to sealed-bid auctions, although here it is used more colloquially and interchangeably with **pay as bid**).

Foreclosure: Denying a rival access to an input (or customer) to weaken competition, such as **strategic investment** in a spectrum auction.

Fragmentation: An allocation of spectrum in a band where operators hold blocks that are not **contiguous**.

Freeriding: Smaller bidders relying on each other to outbid a larger bidder whom they are collectively competing against, so that they each bid below their own **intrinsic value** (leading to a **threshold problem**).

Game theory: A mathematical field in economics used in **auction theory**, to illuminate strategic behaviour and to study conflict and cooperation.

Generic lots: A category of lots in the **principal stage** of a spectrum auction that are not frequency-specific, e.g. a single category of 30 lots of 5 MHz each for the 3.4–3.6 GHz band in the UK's 2018 auction.

GHz: Giga-Hertz, one thousand million Hertz, denoting spectrum frequencies (or amounts).

Hertz: One wave per second, denoting spectrum frequencies (or amounts).

Incentive auction: A two-sided auction where holders of items, e.g. spectrum rights, sell them in a 'reverse auction' and buyers purchase them in a 'forward auction', coordinated by the regulator acting as a clearinghouse (as in the USA in 2016–17 when the sellers were TV broadcasters and the buyers were mobile operators).

Incremental: Causally related additional costs, revenues, benefits, or bids for a specified increment.

Incrementalism: An approach to decision-making using successive limited comparisons or small changes from the pre-existing position (in contrast to considering all possible options with a blank slate).

Information policy: The set of decisions by the regulator on the information to be provided both publicly and to the bidders before, during, and after the auction.

Intrinsic value: Sometimes also referred to as use value, an operator's value from using the spectrum, which is the difference in its expected profit with and without that spectrum, e.g. from **commercial** or **technical value** (without weakening the downstream competitive process, and so excluding any **strategic investment** value).

ITU: International Telecommunications Union.

Licence exemption: No licence is needed to make radio transmissions in the specified frequencies, but there may be rules such as limiting the power of transmissions (as for wi-fi).

Linear price: The same price for each unit, such as multiple lots in an auction (unlike non-linear prices where the price can differ between units).

Lots: The items awarded in an auction. In spectrum auctions, lots are blocks of spectrum in specified bands and defined geographic areas (e.g. national as in most UK auctions, or regional/local as in auctions in the USA). In the auction they are organised into lot categories.

Marginal cost or price: The cost of providing another unit of output, or the price of another unit of consumption – for example, if prices are non-linear, then the marginal price differs from the average price.

Market design: Designing the rules and infrastructure of markets to achieve specified objectives. One branch of market design draws on **auction theory** (and the other on matching theory).

Market division: A strategy of coordinated demand reduction (tacit collusion) between a set of bidders in the auction to acquire spectrum at lower prices.

Market value: The market-clearing price in a well-functioning, competitive market (or the marginal opportunity cost).

MHz: Mega-Hertz, million Hertz, denoting spectrum frequencies (or amounts).

Muddling through: A model of decision-making including **incrementalism**, where means and ends are not distinct, and acceptable outcomes are sought through consensus-building and bargaining, taking a pragmatic approach.

MVNO: Mobile Virtual Network Operator, a retail provider of mobile services that does not have its own network and relies on obtaining wholesale mobile services from network operators (sometimes called Mobile Network Operators, MNOs).

Ofcom: Office of Communications, the UK's regulator for communications services including spectrum management.

Opportunity cost: The cost of a lost opportunity, or the value foregone in the next best alternative, such as an alternative to the current use of spectrum.

Output efficiency: Maximising the incremental gain in net social value in output markets, here **downstream** mobile markets.

Overlay licence: Licensees' rights of use that are limited by the need to respect the presence of earlier incumbent users, and to avoid causing them harmful interference.

Package bidding: Bids for multiple lots as a package that wins or loses in its entirety, as used for example in the **CCA** format.

Paired spectrum: Suitable for using Frequency-Division Duplexing (FDD) technology, where carriers for the uplink from the mobile handset to the base station and downlink from the base station to the handset are in separate frequencies.

Parking: A strategy of bidding for lots in a category, not to win them but to maintain **eligibility**.

Pay as bid: The rule to set payment by the auction winners using the amount in their winning bids (see also **first price**).

Price driving: A strategy where an operator bids above its own **intrinsic value**, not to win the spectrum but to increase the prices paid by its rivals.

Principal stage: The main bidding stage in an auction that determines the amount of spectrum won by each bidder (and if there are **generic lots**, it is followed by an **assignment stage**).

Productive efficiency: Minimising the costs and resource inputs used to supply a given output (such as spectral efficiency in providing mobile data services).

Public value: What is valued by the public or adds value to the public sphere, highlighting longer-term outcomes and processes of value creation in the policy, authorising, and operating environments.

Reserve price: The lowest price at which the seller in an auction is willing to sell the item, and if there is no bid at or above the reserve price, the item will be unsold.

Rational-comprehensive: A model of decision-making with a comprehensive analysis of policy options to assess the most appropriate means to achieve clearly specified objectives, often relying heavily on underlying theory.

SDL: Supplementary downlink spectrum which is used to carry traffic only in one direction from the base station to the consumer's device.

Sealed-bid auction: An auction format that only has a single round of secret bids.

Set-aside: Reservation in the auction of pre-specified spectrum for which only eligible bidders are allowed to compete, such as new entrants.

Second price: The rule to set payment by an auction winner using the highest losing bid.

Signalling: A strategy where bids are used to indicate information to rival bidders, including invitations to coordinate or threats to punish.

Simultaneous auction: Awarding multiple items in the same auction, where bidding is not finished on any item until it has concluded for all items.

SMRA: Simultaneous Multiple Round Ascending Auction, an auction format where there are individual bids for the lots which establish the **standing high bids** in a round, and prices increase in a round if there is excess demand until demand falls so that it no longer exceeds the available supply. Payments by the winning bidders are set according to a **first-price** or pay-as-bid rule.

Sniping: A strategy by a bidder to hide its demand before swooping in at the end of the auction to win.

Social value (or social welfare): Economic welfare from outputs that are valued by economic agents, which is maximised for **economic efficiency**.

Spectrum: The range of frequencies used to transmit information by means of radio waves, denoted in **Hertz**, **MHz**, and **GHz**.

Spectrum floors: Flexible reservation of spectrum, where auction bids are used to determine the specific spectrum reserved from a choice of alternative options (instead of being pre-specified as for **set-aside**).

Standing high bids: The provisional winning bids at each round in the auction used in the **English auction** and **SMRA** formats. They become winning bids in the auction if they are not displaced by higher bids (or withdrawn).

Straightforward bids: Bidding according to **intrinsic value**.

Strategic bids: Deviations from **straightforward bids** by a bidder, usually intended to improve its own auction outcome or worsen its rivals' outcomes.

Strategic demand reduction: An operator bidding for less spectrum than indicated by its **intrinsic value** in order to reduce the price paid in the auction.

Strategic investment: An operator winning spectrum in the auction so as to deny it to rivals and weaken downstream competition.

Substitutes: Alternatives that can be used for the same purpose, such as spectrum in different bands which can be used to provide network capacity, so that a bidder is willing to pay less for one if it acquires the other.

Substitution risk: A bidder wishing to switch its demand between **substitute** spectrum in the auction, but being unable to do so (e.g. because its bids are **standing high bids**).

Sunk cost: A cost that can only be recovered from the activity where it is incurred.

Synergy value: Additional value that arises from **complements**, such as an operator gaining cross-band synergies from having spectrum in two bands for coverage and capacity.

Technical value: An operator's value of spectrum which is derived from avoiding network costs, such as using the spectrum to augment network capacity and avoid costs of **densification**.

Threshold problem: The difficulty for smaller bidders to collectively outbid a larger bidder due to their incentives for **freeriding**.

Uniform price: The same **linear** price for each unit, and the same price to each buyer, such as winners of spectrum in the same lot category.

Unpaired spectrum: Suitable for using Time-Division Duplexing (TDD) technology, where carriers for the uplink from the mobile handset to the base station and downlink from the base station to the handset are separated by time in the same frequency.

Upstream: An earlier point in the supply chain – for example, spectrum is an upstream input used in the **downstream** supply of wireless services.

White space devices: Devices that utilise opportunistic access to pockets of spectrum in specific locations or frequencies which are otherwise unused by the primary spectrum users (such as terrestrial TV broadcasters).

WRC: The **ITU**'s World Radiocommunication Conference.

PART I
Spectrum auctions and public policy decision-making

1. Introducing spectrum auctions

The radio spectrum is a scarce natural resource that we use every day of our lives, whether browsing the internet or checking social media on our smartphones, watching terrestrial or satellite television, listening to the radio, opening car or garage doors with a remote key fob, travelling on taxis, buses, trains, boats, or aeroplanes that use wireless communication, or using the emergency services if something goes wrong. Wireless services have the potential to connect the world, improving communication and contributing to sustainability through better access to clean energy and disaster relief, reduced travel, pollution, and use of power.[1] They can enhance social interactions, media, entertainment, manufacturing, and financial services. For instance, there were 1.35 billion mobile money accounts globally in 2021, providing financial infrastructure otherwise lacking in some low-income countries.[2] Further developments could include connected cars, smart cities, remote healthcare, and farming improvements (such as better management of water consumption).[3]

If companies are to provide wireless services, they need to make radio transmissions in predictable parts of the radio spectrum, and in ways that prevent transmissions interfering with each other or with the many other public service and private sector users of the spectrum. Historically, governments have allocated spectrum licences for rights to make radio transmissions to different companies providing various wireless services on a range of frequencies within their territory. Because of the problems with a free-for-all, in the past states administratively assigned parts of the spectrum to commercial users through a 'beauty contest', where rival companies bid against each other chiefly in terms of claims about the services they would provide and gains to the economy and society. The use of auctions to allocate spectrum licences to potential users making the highest acceptable bids (because those firms place most value on use of the spectrum) was proposed by Ronald Coase more than 60 years ago.[4] At the time it was regarded by policymakers as a bizarre idea – one even asked 'Is this all a big joke?' – because they could not see beyond the prevailing administrative selection processes.[5]

It took time for the advantages of spectrum auctions to be recognised, and so they were only introduced in the 1990s. Their success led to this approach becoming mainstream practice worldwide, in both developing and developed countries.[6] The rest of this chapter first explains the overall importance of spectrum auctions, and then the second section looks at the basic role of the auction regulator in securing 'public value' for widespread benefits to the public, industry, and the economy. The last section gives a brief overview of the rest of Part I, and a sketch outline of the more detailed auction design issues covered in Part II of the book.

How to cite this book chapter:

Myers, Geoffrey (2023) *Spectrum Auctions: Designing markets to benefit the public, industry and the economy*, London: LSE Press, pp. 3–12. https://doi.org/10.31389/lsepress.spa.a.

1.1 The importance of spectrum auctions

A high-value use of spectrum is for cellular mobile services which are now an essential part of people's digital lives almost everywhere across the world for both business and personal use.[7] There were more than 5 billion mobile phone subscribers worldwide in 2020, of which 4 billion used mobile internet, more than half the world's population.[8] In low- and middle-income countries, a majority relied on mobile phones for internet access, including 80 per cent of adults in India. Smartphones are deeply woven into the fabric of life in all higher-income countries – for instance, in 2020 they accounted for almost 70 per cent of all time spent online in the UK.[9]

Mobile technology has continually developed over the last 30 years, with a new generation of phones arriving roughly every decade, facilitated by corresponding phases of spectrum auctions – 2G in the 1990s, 3G in the 2000s, and 4G in the 2010s. The latest round of 5G auctions started in 2017 with Asia, Australasia, Europe, and North America further advanced in this phase than Africa and South America. The process will not stop there. Suitable radio spectrum (whether existing or new) will be needed to deploy 6G technology and move it from a research and development phase to become practical reality for businesses and consumers in the 2030s.[10]

Selling rights to use mobile spectrum via auctions raises revenue for governments. But this is not the most important reason for allocating licences in this way. When future developments are uncertain, auctions provide a good way for governments to identify which users are the most efficient users of the spectrum. If governments assign licences to the right firms, they can facilitate huge consumer value through innovative wireless services on ubiquitous devices. They can also secure public value through extensive take-up, coverage, and access to vital information and public services.[11] The core idea is that auctions can reveal the most efficient and effective mobile providers, because they will be able to bid more and win licences, while also meeting public service obligations laid down by the regulator. An economically efficient allocation maximises social value through assigning scarce resources like spectrum to users that deliver the highest-value outcomes for society. So well-designed spectrum auctions are economically efficient if they allocate parts of the radio spectrum to the best societal use, thereby giving markets a good name. Of course, not everyone agrees this will happen. There are periodic complaints – some legitimate, others flimsy – from mobile operators who have to pay the auction prices, from commentators who question whether spectrum is truly scarce, or from those who hanker after the old days when radio spectrum allocation was routinely used as part of a public interest compact between the government and licensees.[12] (This view continues to hold sway for public broadcasting spectrum in many countries.)

Auctions are increasingly used for mobile spectrum, however, because they can work well. Yet beneath the surface of overall accomplishment, auctions remain risky. There are examples of rousing success, but also some embarrassing failures, and a range of outcomes in between. A key early achievement was the 1994 auction in the USA, which benefitted from a serious use of design expertise in its preparation.[13] Another case examined in detail in this book is the 3G auction in the UK in 2000. At the time it raised more money than ever before in the entire history of auctions, £22.5 billion or $34 billion, and has been called the 'biggest auction ever'.[14] It was subsequently superseded in absolute but not per capita terms, notably by the $81 billion secured for the US government in the 2020–21 (C Band) auction.[15] A further auction analysed in the book is the much lower-profile UK auction for 5G spectrum in 2018. It was competitive and successful, yielding an outcome desirable for consumers through efficient allocation of spectrum bands and promotion of strong retail competition, plus generating revenue of £1.4 billion for the government.

There have also been avoidable failures. A mistake occurs when valuable spectrum is left unsold and not brought into productive use to benefit the public and the economy. Such an outcome has happened in numerous countries. A notable example is India where there was significant unsold spectrum in six of the seven auctions between 2010 and 2021. The 2013 auction in Australia was especially embarrassing for the responsible minister, who set high reserve prices and trumpeted his 'unfettered legal power', proclaiming that, if he told them to, bidders would have to 'wear red underpants on [their] heads'.[16] But he was left red-faced when no bids were made for half the valuable spectrum on offer.[17] Another type of failure occurs when auctions seem to become interminable, such as Finland's 4G auction in 2013,[18] or Portugal's 5G auction in 2021 which lasted for a world-record 1,727 rounds of bidding, stretching over more than nine months.[19] Both 5G deployment and the entry of new firms were eventually enabled in Portugal, but benefits to the public and the economy were unnecessarily delayed.

1.2 Designing markets for public value: some key takeaways

The successes and failures of spectrum auctions follow from specific and detailed public policy choices. Spectrum auctions create a very particular type of market, not occurring 'naturally' but as a result of conscious design of their rules and infrastructure to achieve specified objectives. The common dichotomy drawn between markets on the one hand and regulation on the other is exposed as a false trade-off from this perspective, because regulation for good 'market design' can harness markets to work successfully for the public interest. Doing so entails drawing on auction theory in economics, and combining it with practical know-how and well-informed design choices about numerous issues. Key questions to settle are: which parts of the spectrum to make available for sale, and in what configurations; choosing between different types of auctions, informed by likely patterns of bidding and learning from past experiences of success and failure; facing practical challenges of regulatory decision-making; deciding how to promote competition between suppliers; securing enhanced territorial coverage of mobile networks; and dealing with any litigation battles or implementation problems. None of these matters is a straightforward choice.

States and governments assert their authority to control rights of use for the radio spectrum, because it is a scarce natural resource, owned by the community at large. There are also economic market failures that provide a rationale for spectrum regulation. Radio frequencies are a common pool resource, prone to the 'tragedy of the commons'. Like fish stocks or irrigation systems, there are incentives for self-interested economic actors to over-use the resource. Just as over-fishing depletes fish stocks, so unregulated radio spectrum transmissions risk interfering with each other. One objective of spectrum regulation is economic efficiency, maximising social value from use of the natural resource. However, the approach in this book emphasises 'public value' to provide further breadth, a change that brings into consideration wider values like equity and social cohesion, plus the legitimacy and sustainability of the policymaking process amongst citizens and stakeholders. With this approach, spectrum auctions can be designed to yield wide-ranging benefits to the public both as consumers and as citizens in digital society, to taxpayers through government receipts of auction revenues, to industry by providing access to valuable scarce resources, and to the wider economy via improved mobile infrastructure to support personal and business activities.

The idea of harnessing markets for public value in allocating spectrum through well-designed auctions is now less contentious and has spread further across many countries than for some other natural resources (apart from land). The overall success of spectrum auctions suggests a potential to use markets for other allocation choices, so long as the circumstances are right. However, lessons cannot be simplistically read across from spectrum auctions, because the analysis shows that the *context and details* of auctions matter enormously in achieving desirable outcomes. The history of failures as well as successes provides emphatic illustrations that using markets is far from risk-free. Big-picture policy decisions to use auctions are necessary, but they are not close to sufficient if the finer design points are not right. Effective use of expertise is always crucial in making the required detailed policy judgements.

Design and implementation decisions involve constructively applying theoretical models and knowledge. They cannot be made by simply lifting from text books, but involve practical processes which include people prone to bounded rationality and human biases. In addition, a key lesson of cross-national experience with market design is that it should be an ongoing process of *learning* and adjustment because countries' conditions and the state of knowledge change. No single approach can fit all situations, and auction behaviours change over time as participants in industry and the regulator learn how to improve their strategies to cope with new conditions or requirements. For instance, later chapters show that the UK's spectrum auctions have been mostly successful, but they have also considerably changed in their approach and outcomes over time.

Another recurring theme in the book is that spectrum auction *decision-making* is complex and shows challenges of reputation management, coordination, and interactions between experts and policymakers. Experts can illuminate issues for policy judgement, but they may be more effective if they understand that their role is to assist decision-makers, and not supplant them. Advisers need to be sensitive to policymakers' public value preoccupations and priorities, considerations that often go beyond their own core technical or economic expertise.

A further key takeaway, developed across Part II of the book, is that tailored *analytical frameworks* can assist structured and consistent public policy decisions on the many issues required for successful auctions. For example, the auctions noted in Section 1.1 as failures in India and Australia came about because ministers set reserve prices for selling spectrum blocks that were too high. Meanwhile the auction was so elongated in Portugal partly because the reserve prices set there were too low (along with other design flaws). Using a tailored analytical framework can help improve the art and science of setting reserve prices, guiding the choice to be more or less conservative depending on an informed judgement about the specific balance of risks, and a careful interpretation of the available evidence on market value. Greater uncertainty increases the risks from setting higher reserve prices which are intended to increase revenue or deter strategic bidding if competition in the auction is weak, because the regulator may inadvertently overprice the spectrum. Uncertainty therefore favours setting lower reserve prices that can encourage firms to participate, improve 'price discovery' (their understanding of the spectrum's market value), and mitigate risks of the government being left with unsold spectrum. Part II shows how appropriate analytical frameworks were implemented in the UK's auctions to guide a wide range of design decisions, including to avoid unsold spectrum. These frameworks can also be applied in other countries to assist decision-making for their auctions.

A final takeaway relates to harnessing auctions to *generate information*. The auction bidding process can elicit reliable information that private sector participants do not otherwise have an incentive to reveal, because auctions force them to 'put their money where their mouth is' to win the spectrum they want. Auctions can be designed innovatively to yield information valuable for improving key aspects of policy decisions – such as how to weigh up the costs and benefits of extending high-quality mobile phone coverage to rural and remote areas, a major public concern in most countries. This information-revealing aspect of specific spectrum auction approaches has potential for wider application, for instance, in setting environmental policies or refining public infrastructure procurement.

Therefore, four overarching themes are developed throughout the book. Part I explores challenges of public policy decision-making. It also provides an overview of a case study of UK spectrum auctions, which is then analysed in greater depth in Part II. Tailored analytical frameworks for many design decisions are developed in Part II and shown in action for UK auctions. The UK experience also provides practical examples of harnessing auctions to elicit information to improve public policy decisions.

1.3 The plan of the book: before, during, and after spectrum auctions

Spectrum auctions involve a range of different regulatory activities from beginning to end, reflected in the chapters of the book, which can be loosely compared to multiple courses in a meal from 'soup to nuts'. Like a diner selecting from an à la carte menu, the regulator needs to make a multitude of large and small choices for a fully fledged auction design. At the start of each chapter, there is a digestible bullet-point summary of key points. Here I provide a brief indication of the material covered by each chapter, intended to whet the appetite.

The rest of Part I includes four chapters addressing the broader policy aspects and lessons to be drawn from spectrum auctions. Chapter 2 begins by giving a non-technical introduction to the radio spectrum, namely the range of frequencies over which it is possible to transmit information by means of radio waves. The character of different types of radio waves, and when they become technologically available for commercial uses, are important factors shaping spectrum auctions. The second section of the chapter considers what auctions actually involve, starting with the widely recognised auction design for fine art, where bids are transparent, start low and go higher, and the item is sold if bids reach its reserve price. However, this is only one possible way that auctions can be run, and so the middle part of the chapter outlines the key variants of spectrum auction design. Finally, the chapter concludes by giving an overview of the UK's experience with spectrum auctions, which is the main case referred to throughout the book.

To understand how spectrum auctions can work well, it is important to have a clear idea of what we want them to achieve, and how best to deploy techniques of the market design approach. Chapter 3 starts by explaining spectrum auctions as an example of designed markets. One goal is the usual economists' criterion of maximising economic efficiency and social welfare (assessed in benefit/cost terms). The chapter sets out a range of features of successful markets. But markets can also go wrong – investigating the sources of market failure can provide helpful diagnosis to inform the best response. The outcomes of spectrum auctions are dependent on how the firms bidding for licences behave – for example, they may operate strategically to advance their self-interest. Game theory can help, as the 'science of strategy', to analyse conflict and cooperation between bidders and the regulator, and identify the best auction design.[20] This chapter also highlights the role of expertise in spectrum auction design through a symbiotic relationship between scholarly advances and practical implementation.

Chapter 4 broadens the analysis by explaining how auctions should aim to maximise public value from spectrum sales. This concept is wider than economic efficiency. It recognises that in addition to economic and social welfare gains, some much broader societal values are involved, such as equity and social cohesion for universal mobile coverage. In addition, in a liberal democracy the process by which spectrum allocations take place must be politically appropriate and seen as legitimate by citizens and stakeholders. The independent regulators whom governments normally put in charge of spectrum auctions thus face a complex task. As well as making sound auction design judgements, regulators have to be accountable via consultation processes and act lawfully under threat of judicial review. In a constant glare of publicity and critique, they must actively manage their reputation, both with the public and with industry, including with the often large firms bidding for spectrum.

Beyond the theory of how to run effective auctions, there lies a potentially messier environment, where decision-making can be affected by challenges to make best use of expertise and coordinate relevant activities within a wider political context – the theme explored in Chapter 5. Sufficient expertise is needed to appreciate the risks as lack of understanding of the consequences of incremental changes to established auction designs can be embarrassing (for example, auctions in Finland and Portugal that lasted for nine agonising months). But, to be effective, experts should demonstrate trustworthiness, appreciate wider concerns, and justify their influence in policy debates. Within government, some perennial challenges of coordination between multiple agencies arise, and tensions can exist between experts, regulators, and top political actors. Individual politicians and ministers in relevant fields are stakeholders interested in and affected by auctions, and in some countries are closely involved in decision-making. Their involvement can often complicate the process, as they seek to claim credit for a successful auction and to avoid the 'blame game' that could follow any policy failures.

Some core lessons for public policy decision-making are drawn from the UK's experience of using spectrum auctions in Chapters 3 to 5. The UK is a useful case showing benefits from careful use of expertise to design markets for public value in a medium-sized country. The detailed discussion of how UK auction policies evolved and broadly succeeded is left until Part II. Instead Part I focuses mainly on wider lessons about how to utilise markets to advance public policy goals, such as deploying expertise in market design effectively and linking it to national policymaking, and how to address decision-making biases and coordination challenges.

In Part II the analysis goes much deeper and becomes somewhat more technical at points, while still striving to remaining accessible to any well-informed general reader. To keep things as simple as possible, the basic structure of Part II follows the design and implementation of a spectrum auction in a stage-by-stage way. This approach should also be the most useful ones for officials, scholars, or students who are thinking about how to analyse or progress a particular spectrum auction in any country.

Chapter 6 begins with the foundational choices before developing the auction. Since spectrum is an adaptable input, policy decisions affect the huge array of wireless services, such as changing the use of a frequency band from television broadcasting to mobile broadband, which can then lead to a choice to allocate mobile spectrum licences in an auction. The first part of the chapter explores the strengths and limitations of justifying such a policy decision for change of use, through an impact assessment of costs and benefits. The second part considers why and how spectrum use should be restricted to operators that hold licences, given risks of interference with other users, or instead more freely available to all comers without any need for a licence like wi-fi.

Chapters 7 and 8 explain trade-offs in auction design, navigating the wide range of complexities to design a successful spectrum auction. Chapter 7 considers baseline issues, starting with the specific objectives that policymakers are seeking to achieve with any given auction. Objectives include the efficient allocation of all the available spectrum to bidders, improving the 'downstream' (retail) competition amongst mobile operators that will follow after the auction, and widening mobile coverage across the national population or territory. An objective of gaining revenue for the government is also relevant in some countries (although not the UK). But revenue should generally be subsidiary to the much larger gains for the public and economy from efficient allocation, competition, and coverage. The pursuit of revenue-raising can lead to distortions, such as artificial spectrum scarcity or creating downstream market power, which harm mobile consumers through lower quality, less innovation, or higher prices. For example, a common example of bad practice and regulatory failure is setting reserve prices too high, leading to unsold spectrum.

Chapter 8 sets out the design trade-offs that have to be considered when choosing the type (or 'format') of auction, arguing that, to pursue the objective of efficient allocation, the chosen auction format and detailed rules should encourage bidders to bid straightforwardly in line with their 'intrinsic values' for spectrum blocks. It is a difficult design problem both to facilitate bidders to express the richness of their preferences and to deter strategic bidding which bidders often find more profitable (to reduce the prices they pay or to worsen the outcome for their competitors). The most suitable auction format depends on the applicable circumstances, such as the nature of the spectrum blocks in the auction and the extent to which they are substitutes or complements for each other. This key auction format decision is often choosing between a Simultaneous Multiple Round Ascending Auction (SMRA) or a Combinatorial Clock Auction (CCA). Both involve multiple rounds with prices rising if demand for the spectrum lots exceeds the available supply, but the significant differences of detail and their implications are explained in Chapter 8. At the end of the chapter, a framework is articulated that highlights the strengths and limitations of different auction formats, and assists choice of the most suitable approach.

Promoting competition in the mobile market is the focus of Chapter 9, because the amount and pattern of acquisition of spectrum in an auction can strongly affect the intensity of downstream competition and the consumer experience. There is a desire, therefore, to exclude auction outcomes expected to harm downstream competition and so promote vibrant competition that serves consumers' interests. This chapter shows how to conduct a thorough competition assessment, and balance the risks when choosing measures in the auction such as reservation or spectrum caps.

When private sector bidders take part in an auction, their bids can reveal a good deal of information that is useful for public policy decisions. Chapter 10 explains practical examples of harnessing auctions through sophisticated design for better-informed decisions: using auction bids to choose the best spectrum to reserve to promote mobile competition; and eliciting cost information for policy decisions on mobile coverage extension.

Because spectrum auctions have been ongoing or planned for a long time, and because new rounds of sales are likely to occur in future, it is important to analyse the experiences of each auction once it has been accomplished. Chapter 11 compares the four, mostly successful high-stakes auctions in the UK between 2000 and 2021, highlighting the revenue they generated, assessing how their outcomes matched up against the objectives, and drawing out the lessons for both bidders and regulators for future auctions. The UK regulator's 'horses-for-courses' approach, varying the design to suit specific circumstances, helped to avoid serious mistakes and achieve desirable outcomes. Surprises, which are an occupational hazard of auctions, illustrate the benefits of using auctions to utilise decentralised information held by the companies bidding, compared to regulatory failure risks from centralised administrative allocation like beauty contests. The chapter also analyses the practical implementation decision of how to influence the pace of the auction and avoid problems like the marathon 5G auction in Portugal in 2021.

Finally, the Afterword sets out reflections about the key themes of the book as applied to future auctions: the benefits of avoiding undesirable practices even if also aspiring to best practice informed by the UK case; how policymakers in any country can utilise the analytical frameworks in the book for structured, consistent policy decisions to design spectrum auctions for public value and widespread benefits; and the potential for wider use of auctions in other public policy arenas beyond spectrum allocation.

Notes

1 GSMA (2021c).

2 GSMA (2022).

3 For example, see: Gartner 'Gartner Predicts Outdoor Surveillance Cameras Will Be Largest Market for 5G Internet of Things Solutions Over Next Three Years', Press Release, 17 October 2019, https://perma.cc/ZU29-URCF (connected cars); SmartCitiesWorld 'What 5G means for smart cities', Opinions, 23 October 2019, https://perma.cc/6C9N-832U (smart cities); STL Partners '10 5G Healthcare use cases transforming digital health', https://perma.cc/BV7U-G2MN (remote healthcare); and 5Gradar '10 ways 5G will change farming and agriculture', 6 May 2020, https://perma.cc/URY4-FKHV (farming).

4 Coase (1959); and the first suggestion for spectrum to be awarded to the highest bidder was for television broadcasting by Herzel (1951, p.811).

5 Coase (1998).

6 For example, Koutroumpis and Cave (2018) include auction data from 85 countries in the empirical analysis.

7 Depending on the regime, licences may permit fixed wireless services as well as mobile, and spectrum is auctioned in some countries for other services such as broadcasting.

8 See GSMA 'The Mobile Economy 2021: Infographic', https://perma.cc/AY3H-WU2F.

9 GSMA (2021b, pp.5–6), and Ofcom (2021b, pp.17–18).

10 Samsung (2022).

11 For the USA alone, the Federal Communications Commission has claimed revenue of over $200 billion and benefits of more than $1 trillion: 'Chairwoman Rosenworcel Congratulates FCC's Evan Kwerel', News Release, 28 October 2021, https://perma.cc/NKJ6-3R7C.

12 An example of objections by operators is Vodafone before the UK 2021 auction, reported in BBC News 'Vodafone calls for 5G auction to be scrapped', 16 July 2020, https://perma.cc/JSU6-B336.

13 The 1994 auction in the USA raised revenue of $617 million from spectrum for narrowband Personal Communications Service (PCS), such as nationwide two-way paging services – see FCC 'Auction 1: Nationwide Narrowband (PCS): Net Bids', https://perma.cc/LNZ5-TJHA. More valuable spectrum for broadband PCS spectrum generated $7 billion in an auction in 1995 – see FCC 'Auction 4: Broadband PCS A And B Block: Net Bids', https://perma.cc/E85K-SLW7. This spectrum was allocated for flexible use, including for mobile services competing directly with existing cellular services.

[14] Binmore and Klemperer (2002).

[15] See FCC 'Auction 107: 3.7 GHz Service: Results', https://perma.cc/GV9R-XR4N.

[16] See news.com.au 'Conroy forced to wear red undies of arrogance', 23 January 2013, https://perma.cc/KSK2-TJ2A.

[17] See ACMA 'Auction summary – 700 MHz (Digital Dividend) and 2.5 GHz band reallocation (2013): Results, Total spectrum unsold', https://www.acma.gov.au/auction-summary-700-mhz-digital-dividend-and-25-ghz-band-reallocation-2013.

[18] See ZD Net 'Stuck in an infinite loop: Finland's 4G auctions suspended over bid resetting', 13 September 2013, https://www.zdnet.com/article/stuck-in-an-infinite-loop-finlands-4g-auctions-suspended-over-bid-resetting/.

[19] See ANACOM 'Results of auction bidding phases', 27 October 2021, https://perma.cc/2XUK-LHSA.

[20] See Investopedia 'Game Theory Definition', 2 February 2022, https://perma.cc/9L4Z-7F7Z.

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Note: [open access icon] means an open access publication.

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2. Understanding the radio spectrum, auctions, and the UK case

Tackling public policy problems always involves mastering a certain amount of subject-specific background. To explain what is happening in spectrum auctions I need to say a few words about the radio spectrum in the first section, and about how auctions can be run in the second section. To help keep things concrete, the last section of the chapter outlines the UK's experience with spectrum auctions.

2.1 Radio spectrum: the basics

Summary

- The radio spectrum is the range of electromagnetic radiation frequencies where information can be transmitted using radio waves. The focus in this book is on the frequencies used for mobile services, chiefly denoted in terms of mega-Hertz (MHz) or giga-Hertz (GHz).
- Frequency bands differ in their technical characteristics, with a trade-off between range and bandwidth. Equipment development also makes some bands more desirable, given that mobile handset markets are global. While a band can be used over time for different technologies, certain bands are prioritised for carrying each new generation of technology, as most recently with 5G.
- There is regulation at country level to manage interference between spectrum users. In addition, radio transmissions cross national boundaries, so international coordination is managed through regulation at different levels: at global level, in world regions (like Europe), and bilaterally between neighbouring countries.
- New bands for mobile spectrum come from a range of sources. They may have been used previously by public sector or commercial users, or made available by technology advances (as occurred when TV broadcasting moved from analogue to digital technology, creating a 'digital dividend' of bands freed up for mobile use).

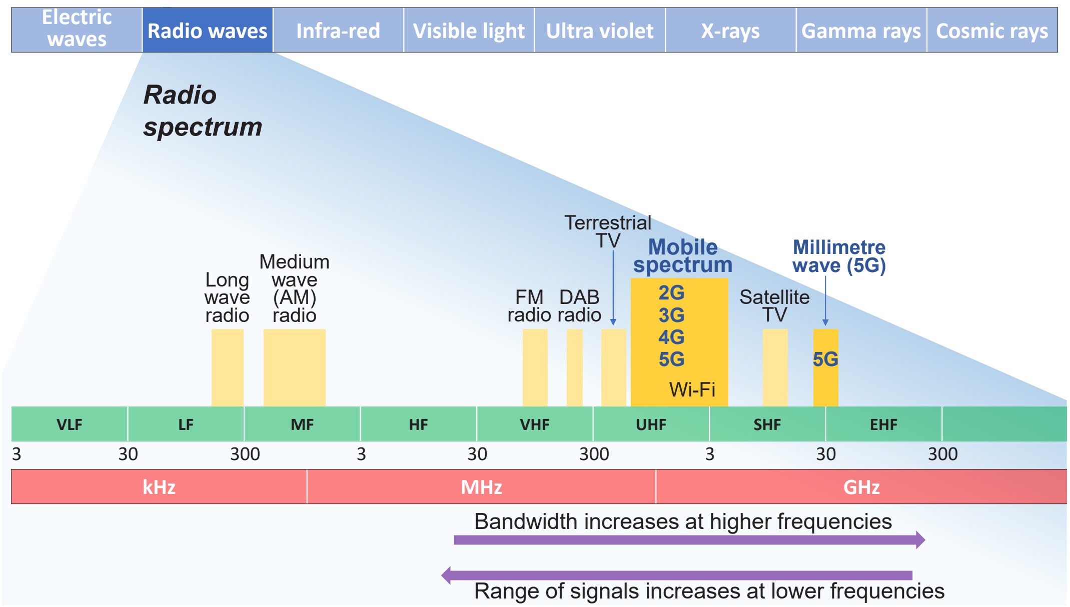
How to cite this book chapter:

Myers, Geoffrey (2023) *Spectrum Auctions: Designing markets to benefit the public, industry and the economy*, London: LSE Press, pp. 13–33. https://doi.org/10.31389/lsepress.spa.b.

The 'radio spectrum' denotes the range of frequencies over which it is possible to transmit information by means of radio waves. Radio waves are a form of electromagnetic radiation, and the top bar of Figure 2.1 shows that they fall between electric waves on the one hand, and infrared radiation on the other. The figure also shows how radio waves can in turn be split up according to their frequency, denoted in Hertz, or multiples of thousands as kilo-Hertz ('kHz'), millions as mega-Hz ('MHz'), or thousand-millions as giga-Hz ('GHz').[1] Different parts of these frequencies within the radio spectrum are used for radio broadcasting, television broadcasting, and mobile services, as well as many other uses.

Radio spectrum is a natural resource owned by society. It is an adaptable input that can be used for a huge array of public and private wireless services. Each national government affects the use of spectrum in its territory, by deciding the allocation of rights to make radio transmissions. Because radio signals in neighbouring frequencies or locations can interfere with each other, each country issues licences for rights to make radio transmissions, to manage interference between spectrum users. In the case of cellular or mobile telecommunications services, the allocation decisions also determine which firms become the country's mobile operators, normally through exclusive licences for specified frequencies including terms and conditions set by the regulator. Within these limits, operators have flexibility to use their allocated spectrum to provide connections over their radio network between a base station and consumers' devices such as smartphones, to transmit calls, texts, and mobile access to the internet. Each mobile network provides wide area coverage so that its customers can receive services where they live, work, and move around. In addition, the amount of network capacity provided in each area affects the quality of services, such as the speed of internet access, as well as the number

Figure 2.1. An overview of the radio spectrum used for radio, television, and mobile services



Source: Author.[2]

Notes: VLF Very low frequency, LF Low frequency, MF Medium frequency, HF High frequency, VHF Very high frequency, UHF Ultra high frequency, SHF Super high frequency, EHF Extremely high frequency.

of customers that can be served. Each network therefore needs to invest in building base stations to provide both coverage and capacity using the spectrum it holds. For example, the population or country area covered by an operator is affected by commercial considerations, but also by the coverage requirements normally included in licence conditions set by the regulator. The amount of capacity can vary substantially between areas, with much more needed to serve high demand in densely populated parts of the country than in low-density rural areas.

The bottom arrows in Figure 2.1 indicate a technical trade-off between the range of the radio signals and the amount of information that can be transmitted, which is termed bandwidth. For instance, we can compare medium wave (AM) and frequency modulation (FM) radio. Broadcasts of medium-wave radio stations use lower frequencies and so provide wider geographic coverage. But because they have less bandwidth, their quality of sound for speech or music is lower than that offered by FM radio stations, which broadcast at higher frequencies with smaller coverage footprints. For mobile networks, this trade-off means that greater information can be carried at higher frequencies, such as faster data speeds, but more base stations need to be installed to cover a country's territory. Therefore, higher frequencies are especially suitable for providing additional network capacity ('capacity spectrum'), whereas lower frequencies allow wide area coverage to be provided at lower cost ('coverage spectrum').

Mobile spectrum bands

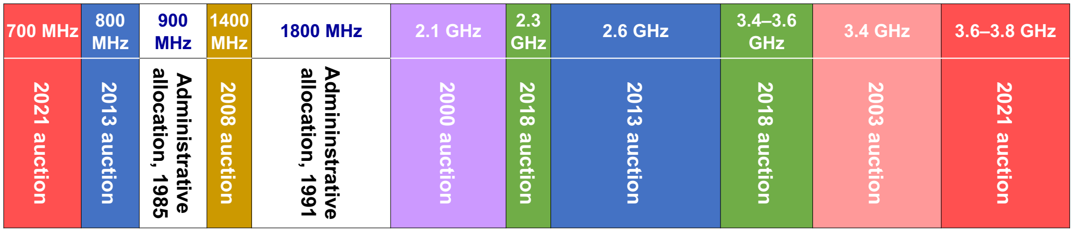
Different frequency ranges are organised into spectrum bands, and the main ones for UK mobile services are shown in Figure 2.2. The first few bands on the left-hand side are lower-frequency coverage spectrum, and the bands on the right-hand side are higher-frequency capacity spectrum. The bands all fall within the set of frequencies shown in Figure 2.1 that offer an especially attractive balance between range and bandwidth. In addition, new technology developments bring ever higher frequencies into use for mobile networks – for instance, for 5G services the millimetre wave spectrum from around 20 GHz upwards which is well beyond the right-hand side of Figure 2.2.

The times when different bands were allocated in the UK and the methods used are also shown in Figure 2.2. The earliest bands (coloured white) were allocated administratively in 1985 and 1991. Auctions were first used in 2000 to allocate the band shown coloured purple, and then in 2003 (pink). There was a decade gap before the bands in blue were auctioned in 2013, with the bands in green following in 2018, and in red in 2021.

As a scarce resource, most radio spectrum is in use, but changes in technology and international and national regulation can lead to the repurposing of bands. The bands in Figure 2.2 became available from a range of sources. Historically, the public sector and broadcasting have been major users of spectrum now used for mobile. The low-frequency bands included in the 2013 and 2021 auctions are sometimes referred to as the 'digital dividend', because they were made available by moving terrestrial television broadcasters to alternative frequencies as part of the shift from analogue to digital broadcasting technology. The bands included in the 2018 auction were previously used by the Ministry of Defence.

In nearly all countries, mobile services are delivered to the public through competition between mobile operators. Competitive markets usually deliver desirable outcomes for consumers and the economy, even if there can be exceptions. Competition applies pressure on firms to reduce their costs, economise on resources, and attract customers by offering lower prices and new or better services,

Figure 2.2. Mobile spectrum bands and how they were allocated in the UK



Source: Author from Ofcom auction documents.
Notes: Both frequency and amount of spectrum are denoted in MHz or GHz. The label is the frequency band and the relative amount of spectrum in each band is indicated by the width of the column.

such as through innovation reflecting the latest technological developments. Competition can empower consumers through greater choice, allowing them to 'vote with their feet' if they are dissatisfied. Competition also generally enhances the level of productivity in the economy.[3]

Some mobile operators are owned in whole or in part by governments, and others are private companies. Economies of scale in mobile networks lead to oligopolistic markets, usually with three to five competing mobile network operators in each country (with additional local operators in some countries). In the retail market, there are also further retail competitors, such as Mobile Virtual Network Operators (MVNOs) who do not have their own radio networks but rely on obtaining wholesale services from network operators. Examples in the UK are well-known consumer brands such as Tesco Mobile, or landline operators like Sky and TalkTalk. In the UK in 2022 there are four national mobile network operators – EE, H3G (whose brand name is 'Three'), Telefónica (using the brand name 'O_2'), and Vodafone. These private corporations hold rights to use all the spectrum bands in Figure 2.2, acquired either via administrative allocation in 1985 and 1991, or via competing in spectrum auctions since 2000 (or through post-auction licence trades). For operators, holding a licence is a critical 'upstream' input and resource. The pattern of spectrum holdings between operators affects the intensity of their 'downstream' competition at the wholesale level to supply MVNOs and in the retail market, where consumers buy their mobile subscriptions and bundles of data services, texts, and telephone calls.

For each network operator the composition of bands in its spectrum portfolio matters, as well as the amount of spectrum held, because bands differ in their technical characteristics. We have seen that lower-frequency spectrum is more valuable in providing coverage in rural areas, such as sub-1 GHz bands at 700 MHz, 800 MHz, and 900 MHz. This is because the greater transmission range means that fewer base stations are needed, thereby economising on network costs. However, in areas with a large volume of traffic there is a limit to how much this matters, because a base station using a single frequency band will not provide enough capacity for services to all the network's customers in that area. One important way to augment capacity is to serve the geographic area with two or more base stations (sometimes called network 'densification'). In this case the theoretical maximum range of the frequency band is not the binding constraint, and having higher-frequency capacity spectrum offers bandwidth advantages. Other ways to augment network capacity include deploying more spectrum and using the latest technologies that achieve more data-carrying capacity per MHz.

The development of mobile equipment is also very important for the valuation and use of spectrum. Handsets are part of a worldwide market, and different bands are prioritised for each wave of mobile technology. For example, the first bands allocated in the UK to mobile operators were 900 MHz in 1985 and 1800 MHz in 1991, both initially used for 1G technology. Over time, use of these bands was progressively converted (or 're-farmed') to the later technologies of 2G, 3G, 4G, and in due course to 5G. The first band deployed in 3G handsets was 2.1 GHz, awarded in the 2000 auction. Early 4G spectrum included the 800 MHz and 2.6 GHz bands in the 2013 auction, but there was also equipment development for the pre-existing 1800 MHz band, so that in the UK this was the first band used for 4G technology. For 5G, the early bands in Europe have been at higher frequencies (due to their bandwidth advantages), especially the last three blocks on the right-hand side of Figure 2.2, which together span the frequency ranges of 3.4–3.8 GHz. In time, new equipment developments should enable any of the bands in Figure 2.2 to be re-farmed for 5G technology.

Across countries there is often similarity in the frequency bands used for mobile services, reflecting equipment manufacturers' economies of scale in producing handsets, so that it is difficult for all but the very largest countries to go their own way in choice of spectrum bands for mass-market services like cellular mobile. But there are variations between regions and continents, due to differences in historical spectrum use and priorities. For instance, while 900 MHz and 1800 MHz were the earliest bands used for mobile services in the UK, in the Americas the initial bands were 850 MHz and 1900 MHz.[4] Since radio transmissions cross national boundaries, a complex web of coordinating regulation is also needed at different levels. Some is global, some in large world regions (like Europe), and others bilateral between countries that share borders. The worldwide regulatory body is the International Telecommunications Union (ITU), which holds a World Radiocommunication Conference (WRC) every three to four years.

Whether regulators decide to use auctions or another method to allocate mobile bands, they will necessarily have to make a range of choices about the regulatory conditions for licences, including:

- Geographic scope: In the UK, mobile spectrum licences have usually been defined on a national basis, but in some other countries there are regional or local licences (such as Australia, Canada, India, and the USA).
- Services or technology: Historically, licences restricted spectrum use to specific services or technologies to manage interference. However, over time there has been a move to greater flexibility through terms that are more technology-neutral.
- Duration: Because the investment needed to create a mobile network requires firms to incur large sunk costs, mobile spectrum licences tend to last for many years, for example 10, 15, or 20 years. At the end of this period, there are renewals or a competitive selection process. In some countries like the UK, companies have been assigned licences of indefinite duration, with no specified end-date.

2.2 Introduction to auctions

When licences are initially allocated, the regulator can use different methods to decide who gets to hold a spectrum licence. Because mobile services are a technologically and commercially dynamic field, it is especially difficult for a regulator to judge which will be the most efficient licensees for periods stretching many years into the future. One simple approach is 'first-come, first-served', where licences are allocated in the order of firms applying for them. However, where there is excess demand from companies for spectrum bands, this is not an effective way to secure economic efficiency, maximise

Summary

- Licences for mobile spectrum bands can be allocated to companies using administrative methods (such as a 'beauty contest' or a lottery) or via spectrum auctions.
- An auction is one type of market mechanism to sell items, where the outcome is determined based on eliciting information through bids from competing buyers about their willingness to pay.
- There are many possible auction formats. One is an open, ascending-price auction as used in fine art auctions. Other auction formats are more suitable for radio spectrum, given differences in objectives and context, most commonly the Simultaneous Multiple Round Ascending Auction (SMRA) or the Combinatorial Clock Auction (CCA).
- Prominent objectives of spectrum auctions are efficient allocation and public value, not just revenue (even if that tends to dominate media coverage).
- Unlike the single item in a fine art auction, spectrum auctions usually award multiple blocks of spectrum simultaneously to several winning bidders who may regard them as substitutes or complements to varying degrees.
- There is usually only a handful of companies bidding in spectrum auctions, given that mobile markets are oligopolies (due to economies of scale and scope), increasing the opportunities for strategic bidding.
- With these challenges, there is no perfect spectrum auction design, and experts embedded in practical public policy processes contribute to good judgement of the inevitable trade-offs.

benefits to consumers, or yield revenue for the government. In the past, lotteries were used in the USA at times, with luck alone determining which companies were initially successful (followed by the potential for subsequent licence trading). More usually there is a competitive allocation process. Before the 1990s such processes often took the form of a 'beauty contest', where the regulator applied specified criteria to judge the allocation between bidders. In the UK only the two original bands (900 MHz and 1800 MHz) in Figure 2.2 were administratively allocated through a beauty contest, but that method continues to be used to allocate spectrum for broadcasting.

Auctions with monetary bids are the other main competitive process. An auction is a type of market mechanism used by an auctioneer to sell (or buy) items, where the outcome is determined based on eliciting information through bids from competing buyers (or sellers) about their willingness to pay (or sell). For example, in an auction for a famous painting, dynamic interaction between competing buyers determines both the winner as the highest bidder and the price it pays. Compared to other allocation methods, auctions have the advantage of using a very transparent criterion to select who gets what. Money is an objective metric unlike the opaque, subjective judgement calls that can be features of beauty contests. Using monetary bids is suitable where the interests of consumers and public value are reflected in the regulatory conditions of sale, such as licence obligations to provide widespread mobile coverage and safeguards to promote downstream retail competition.[5] In the UK,

Figure 2.2 shows that, once adopted, auctions have been used to allocate the large majority of mobile spectrum (80 per cent).

Auctions have been used throughout world history for selling a wide variety of goods and services. A few examples are auctions for commodities, flowers, fish, companies, residential houses, antiques, broadcasting rights, service contracts for sport stars (such as cricketers in the Indian Premier League[6]), government Treasury bills, electricity, oil exploration and development leases, emission permits, and subsidies (an example from 2021 being environmental protection of turtle doves[7]). Auctions involve a structured bidding process amongst rivals to determine the winner and set the price. Of course, in contrast, many other products and services are bought and sold at prices posted by the seller, such as buying food from a supermarket or a mobile phone subscription from a retail communications provider. Even if there is sometimes room for haggling over the price, this tends to be a bilateral process between one buyer and one seller.

In the popular imagination, an auction often conjures up an image of an auctioneer at a podium with gavel in hand selling an item, such as a fine art painting, to multiple potential buyers in the room. The auctioneer responds to a previous bid by seeking bids at the next price up, and rivals in the room announce ever higher prices, until there is a single winner. This was the process used to sell the most expensive painting sold at auction, Leonardo da Vinci's *Salvator Mundi*, for $450 million in 2017.[8] However, this is just one specific context for an auction using one of many possible formats, and auctions can be structured in many different ways.[9]

The context for spectrum auctions is the different players involved and their interests:

- Auctions are organised and run by a regulator, whose chosen design depends on its objectives, such as allocating the spectrum in economically efficient ways, and promoting downstream mobile competition and extensive mobile coverage. To achieve these objectives, and with measures in the auction to safeguard competition and extend coverage, the regulator wants to incentivise bidders to make straightforward bids of the values they place on the spectrum in the auction. Assigning spectrum to the operators with the highest values is likely to deliver the largest benefits to the public. It is also important that the process is fair and seen to be fair, especially given the large sums of money involved. In many countries, the regulator is an independent agency, such as Ofcom in the UK or Anatel in Brazil, with its own statutory duties and authority to make decisions within a defined remit, separate from government and the political process. However, in some countries that regulatory role is performed by a state ministry, such as 'Innovation, Science, and Economic Development Canada' or the Department of Telecommunications in India.
- The government sets the overall direction of policy, and sometimes more detailed policy goals. In addition to boosting efficiency, competition, and coverage, ministers and top administrators are interested in the significant revenue that can be raised by spectrum auctions. Without an independent regulator, the governmental and regulatory functions for the auction can be performed by the same public organisation (as in Canada and India).
- The bidders in spectrum auctions normally include existing (incumbent) operators – in the UK: EE, H3G, Telefónica, and Vodafone – and sometimes also potential new entrants. Operators acquire spectrum licences at lump-sum prices set dynamically in the auction, and they take on the risk of using the spectrum to provide and sell services to earn profits, which can turn out to be higher or lower than they expected at the time of the auction. These firms are motivated by complex profit and commercial goals, and given the relatively small number

of bidders in spectrum auctions, they can often further their business goals by bidding strategically instead of straightforwardly. For example, self-interest might lead a bidder to seek to improve its outcome, winning spectrum at lower prices through bid strategies to exploit reduced intensity of competition in the auction. Or it might attempt to disadvantage its rivals. For example, one strategy is to bid up the auction prices that the rivals have to pay for spectrum. Another is to acquire more spectrum than it actually needs to stop rivals from winning spectrum, anticipating that it can later push up prices to consumers in a less competitive retail mobile market to recoup the initial outlay. Especially for high-stakes billion-pound auctions, it is common for large operators to undertake substantial preparation and engage world-class auction experts to advise them on bid strategies.

- The public, citizens, and mobile consumers do not directly participate in auctions. But a key role of the regulator is to represent their interests, which can be strongly affected by the outcomes that shape levels of industry investment, pace of innovation, strength of downstream competition, extent of network coverage, and the quality and prices of mobile services that consumers receive.

This context means there are important sources of complication in spectrum auctions when compared to auctioning the da Vinci painting. Selling a painting usually has a single objective—to maximise revenue. Spectrum auctions have multiple objectives to be balanced: efficient allocation, competition, coverage, and sometimes also revenue. It is true that, for spectrum auctions, the media often focus on the revenue raised. In the UK the 2000 auction generated exceptionally high revenues for the government of £22.5 billion, while the money raised in the 2013 auction was almost ten times lower at £2.4 billion. Does that make the first a success and the later one a failure? Not at all, because the outcomes in economic welfare for consumers, public value, and the wider economy from spectrum auctions are far larger and much more important than the revenue raised. Auctions designed to maximise revenue can damage efficient allocation and weaken retail competition, leading to more expensive and lower quality services for mobile consumers.

A second key difference is that the da Vinci auction sold a single item to one winning bidder, whereas spectrum auctions usually award multiple blocks of spectrum (or 'lots') to several different winners. The bidders may regard the different lots, to varying degrees, as substitutes for each other ('if we win lot A, we don't need lot B'), or as complements where the whole is worth more than the sum of the parts ('if we win lot C, our value for lot D increases'). These considerations complicate bid strategies because a bidder's value for a lot depends on what else it wins.

A third key difference from art auctions, which can attract a large number of bidders, is that spectrum auctions normally involve only a handful of rival contenders – given that mobile markets tend towards being oligopolies. The small number of operators opens up various strategic opportunities for a bidder to improve its own auction outcome or disadvantage rivals. A further source of complication is that the outcome of the upstream auction for spectrum can also affect the terms of downstream competition and the quality of mobile coverage experienced by the public.

The regulator's fundamental design challenge for the auction is to specify a market process providing self-interested companies competing for spectrum with desirable bidding incentives, so that the auction outcomes achieve the public policy objectives. However, the complications mean there is no perfect design for spectrum auctions to guarantee this. Instead the regulator needs to use judgement about multiple trade-offs in the design decisions. Many interrelated choices have to be made, including the following building blocks:

- Open auctions mean that full information about all bids made in each round is available to all bidders. Closed auctions mean that bidders have no information about the secret bids made by other bidders. In partially open auctions, some but not all information about bids is provided to rival bidders.
- A single lot can be sold per auction, with multiple items perhaps sold in a series of sequential auctions one after the other. Alternatively, an auction can offer multiple lots simultaneously – a simultaneous auction finalises the sale of a lot only after it has identified a winner for all other available lots.
- Auctions can take place with just a single round of bidding (so bidders have a 'one-shot' opportunity only). Or there can be multiple rounds, allowing prices and bidders' demand for the lot(s) to evolve across a series of rounds.
- If there are multiple rounds, there can be ascending prices from one round to the next, such as starting from a low reserve price and continuing to rise until demand from the bidders that are still active matches the available supply. Alternatively, a 'Dutch' auction has descending prices, starting from a high level at which demand from bidders will be below supply and progressively reducing prices across the rounds until the price is low enough that the market clears with the lots sold.
- Bids can take the form of bidders specifying a price for each desired lot. Alternatively, in a 'clock' auction, the auctioneer announces fixed prices in each round and bids are made for the quantities desired at that price. (Despite the name, there is no fixed time limit in a clock auction, and instead the label derives from the large clock face that was used to indicate prices in auctions of tulips in the Netherlands, now displayed electronically).[10]
- Bidders can make individual bids for the lots they want, some of which can win and others lose. Alternatively, in a 'combinatorial' or 'package' auction, bids are for packages of lots which either win or lose in their entirety.
- A winning bidder can pay the price at which it made its winning bid (called a 'pay-as-bid' or 'first-price' rule). Alternatively, with a 'second-price' rule, the price paid by a winning bidder is not set by its own bid but instead by the highest losing bid from another bidder.

These building blocks can be combined in different ways to create many alternative auction formats. Fine art is usually sold in an open, ascending-price, multiple-round auction for a single lot, with bidders making individual bids by specifying a higher price (or responding to the auctioneer's price announcements) to displace the 'standing high bid', and the winner pays the price in its bid (called an 'English' auction).[11] Some spectrum auctions use sealed bids in a single round of bidding, and there are examples with either a single licence being awarded or with multiple lots offered simultaneously; and these contests can involve either individual or package bids and either first- or second-price rules.

More commonly, spectrum auctions are partially open, ascending-price, multiple-round auctions for many lots simultaneously:

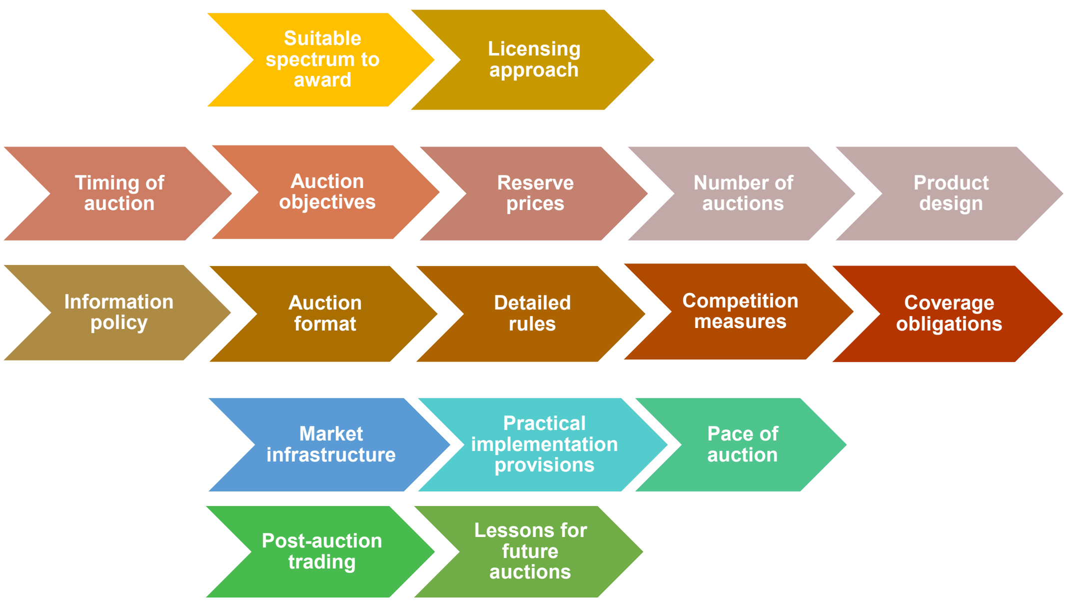
- One of the main formats is the Simultaneous Multiple Round Ascending Auction (SMRA) in which there are individual bids for lots specified in both prices and quantities. A pay-as-bid, first-price rule applies to the winning bids (although in this format it effectively operates similarly to a second-price rule, because a winner only needs to just outbid the highest losing bid).[12]

- The other main format is the Combinatorial Clock Auction (CCA). This is a package auction with two stages, first a clock auction, followed by a single round of sealed bids in which bidders make mutually exclusive bids on as many different packages as they want. However, at most one of these bids can win, and payments by the winning bidders are set according to a second-price rule.

Each auction format is better seen as a family of designs, because many important details affect the ability of bids to fully express companies' spectrum values (which are complicated by interdependencies where lots are substitutes or complements), their incentives for strategic bidding, and the prospects for efficient allocation and revenue. Understanding these considerations and how they are significant in the circumstances of each auction is a key area for expert judgement of trade-offs to decide the specific auction design.

The range of large and small regulatory choices for a fully fledged auction design are illustrated in Figure 2.3, and explored in detail mostly in Part II. Prior steps are in the first row: obtaining suitable spectrum to award, and choosing the licensing approach (Chapter 6). Then there is the question of auction timing and many aspects of designing the auction in the second and third rows: identifying the right objectives, judging the level of reserve prices, deciding the number of auctions, the product design, or granularity of spectrum to be bid for, and the amount of information to be provided to bidders and the public (Chapter 7); choosing the auction format and detailed rules (Chapter 8); assessing the best competition measures (Chapter 9) and coverage obligations (Section 5.3); or harnessing auctions in innovative ways to improve policy choices about them (Chapter 10). The overall

Figure 2.3. Range of decisions for a spectrum auction



Source: Author.

characteristics of the auction depend on how all these design elements fit together. After the design decisions, the fourth row shows the regulator's tasks to run the auction, which means providing market infrastructure including an electronic auction platform, and other operational or practical implementation provisions such as auction rooms and security arrangements; and managing the pace of auction bidding. Finally, in the fifth row there are post-auction events of facilitating spectrum swaps or trades between operators, and learning lessons for future auctions (Chapter 11). For all these decisions, across the chapters I draw out analytical frameworks relevant to making well-structured and consistent public policy choices. These frameworks are shown in action for UK auctions and can also be applied to spectrum auctions throughout the world.

2.3 Overview of UK auctions

Summary

- The UK provides an interesting central case study for analysing key issues in spectrum auctions. Four high-stakes auctions offer differing experiences of scale, surprises, and complications, yet within an overall narrative of learning and adapting.
- The UK auctions have been mostly successful through the regulator making auction design choices attuned to the circumstances and imposing well-judged competition measures to promote downstream competition. Varied approaches have been adopted to the important public policy concern of improving mobile coverage.

The UK's experience with spectrum auctions offers insights that are also relevant to other countries for several reasons. The UK regulator, Ofcom, has consistently sought to apply expertise to the auction design choices and adapted to different circumstances. It has been willing to take risks with innovative designs. By contrast, some countries, such as Germany, have stuck with a familiar design. In addition, as a medium-sized and stable liberal democracy, the UK case offers insights into the challenges of decision-making involving multiple public organisations and a range of professional skills.

The UK regulator developed an especially structured and thorough approach to assessing the downstream competition effects of auctions, which guided its choice of proportionate competition measures. The UK mobile market has been amongst the more competitive mobile markets internationally, assisted by consistent and proactive use of measures in spectrum auctions designed to promote strong competition, such as caps on the amount of spectrum that any one operator can hold and more interventionist reservation of spectrum blocks.

Everyone knows the frustration when your mobile service fails to achieve a useable signal in different locations. Operators want to supply busy urban markets, but it is less profitable to invest in new infrastructure in low-traffic areas, for instance, in some rural parts of the country. So improving the extent and quality of mobile coverage is a key public policy concern for regulators and governments worldwide. 'Coverage obligations' on operators offer one way to address this issue, and can be included in spectrum auctions. The UK has taken different approaches over time, illustrating both the advantages and pitfalls of coverage obligations in auctions compared to alternatives – such as governments negotiating with mobile operators to procure coverage directly in hard-to-serve areas.

Figure 2.4 gives an overview of four high-stakes UK auctions used as reference points throughout the book to illustrate concepts and analyse key issues. The heading column shows the auction name and gives a thumbnail description of the outcome. The first column after that shows the date of the auction and the format used for it. The variation in format between auctions reflected conscious choices by the regulator to adapt to circumstances. All the auctions awarded multiple spectrum licences simultaneously, which is important where operators' demand for the lots is interrelated, but the salient aspects of demand were different between auctions:

- The SMRA format for the 2000 auction awarded five licences in one band which were *substitutes*, allowing bidders to switch between them depending on their relative prices in that round in the auction.
- A challenge for the next high-stakes auction in 2013 was that the different coverage and capacity spectrum bands were *complements* for some operators with synergy values, so that the whole was worth more to them than sum of the parts.[13] Accordingly, the regulator chose a different auction format, CCA, with package bids enabling firms to express the complementary value of winning spectrum in both bands. However, package bidding introduces complications, so it comes with disadvantages as well as strengths, such as opportunities for certain types of strategic bidding (e.g. to disadvantage rivals).
- The 2018 and 2021 auctions involved multiple spectrum bands, but there was less evidence of significant synergies in operators' values, which made the simpler SMRA format suitable in both cases.

The second column in Figure 2.4 shows the amount of revenue generated for the UK government by the auctions, which was massively greater in 2000 than in later auctions. The 2000 auction took place at the height of a stock market boom, and at that time the industry had little experience with spectrum auctions either in the UK or internationally, which perhaps contributed to 'overbidding'. In later auctions, bids were less aggressive. Revenue raised by each spectrum auction tends to dominate their media coverage, but compared with other aspects of the outcome (such as economic and social benefits from efficient allocation, strong downstream competition, and improved mobile coverage), the sums raised are much less important.

The third column in Figure 2.4 shows how many winners there were out of the total number of bidders, and the fourth column shows the number of bidding days which reduced across the period. Promoting downstream mobile competition remained an objective of the regulator in all four auctions, and it used a consistent analytical framework. As set out in the penultimate column, the more interventionist policy of reserving some spectrum was used for the 2000 and 2013 auctions (and subsequently vindicated because it supported sustainable competition). However, it was not seen as necessary or proportionate in the 2018 or 2021 auctions, which used only spectrum caps. The final column in Figure 2.4 indicates coverage obligations that were attached to some of the auctioned spectrum licences. Such provisions can contribute to operators extending mobile coverage. But they are far from problem-free, running the risk of overpromising and under-delivering for consumers. Alternative policy approaches can be adopted, and over time the UK government has moved more

Figure 2.4. Summary information on high-stakes UK auctions

Auction name, description	Year and auction format	Revenue in £ billion	Number of winners (and bidders)	Number of bidding days	Competition measures	Coverage obligations
3G auction: 'Biggest auction ever'	2000 SMRA	22.5	5 (of 13)	36	Reservation for a new entrant Maximum of 1 licence per bidder	All 5 licences required 80% population coverage by the end of 2007
4G auction: 'Surprises and complications'	2013 CCA	2.4	5 (of 7)	14	Flexible reservation 2 spectrum caps	1 licence: 98% of premises indoors by the end of 2017
PSSR auction: 'Widely seen as successful'	2018 SMRA	1.4	4 (of 5)	10	2 spectrum caps	n/a
5G auction: 'Short and sweet?'	2021 SMRA	1.4	4 (of 4)	3	1 spectrum cap	Superseded by a government agreement with the operators

Source: Author from National Audit Office (2001) and Ofcom auction documents.
Notes: SMRA: Simultaneous Multiple Round Ascending Auction; CCA: Combinatorial Clock Auction; PSSR: Public Sector Spectrum Release (because the 2018 auction spectrum was released by the Ministry of Defence).

towards direct procurement from mobile operators as a way of improving coverage. In the remainder of the section I give a brief account of each of the four UK auctions (see Section 11.1 and Annex A for further details).

3G auction in 2000: the 'biggest auction ever'

The UK's first spectrum auction was a humdinger. Assisted by heavy pre-auction marketing, there was an unusually large number of bidders leading to very strong competition in the auction, a lengthy bidding duration of 36 days, and extremely high prices. The auction raised revenue from licence sales of £22.5 billion, which was 45 times larger than the reserve prices set at £500 million (and an order of magnitude larger than the official pre-auction revenue forecast of £1–3 billion). Four of the five eventual winners in the auction were the incumbent national mobile operators (at the time BT, One2One, Orange, and Vodafone). The last winner, H3G, was victorious after out-competing eight rival bidders for the 'set-aside' spectrum licence reserved for a new entrant.

There are several explanations for the startlingly high and never-repeated revenue. At the height of a telecommunications stock market boom, the prospects for new market entry seemed especially bright, and incumbent firms were convinced that their future viability depended on winning a 3G spectrum licence. A 'winner's curse' effect may have been fuelled by stock market expectations, fear of losing, and managerial overconfidence about the commercial prospects of 3G which was regarded by some at the time as heralding a new world of mobile internet. The industry and bidders were also less experienced with auctions. Observers were amazed as prices continued to go up and up to become the highest-revenue auction then ever seen in history. News reports referred to 'staggering sums of money'.[14]

In assessing the outcome we should distinguish between the allocation to the winners which looks economically efficient, and the prices paid which seem to have resulted from overbidding. With the benefit of hindsight we can see that 3G did not lead to such a large step-change in mobile services, and Peter Bonfield, BT's chief executive, later said that the industry 'spent £10 billion too much'.[15] After the telecommunications stock market boom, the bust followed on the tails of this auction. Bidders learned lessons from their mistakes in the UK's 3G auction and the similarly high prices in Germany's 3G auction later in 2000, and governments gained much lower revenues in later auctions, both in the UK and in most overseas sales.

The 2000 auction was a clear success in reserving spectrum for a new entrant. The beneficial boost to downstream mobile competition has been long-lived. While H3G (using 'Three' as its brand name) remained the smallest operator throughout the two decades since the 2000 auction, it was also an important competitive force. H3G was the first network to launch 3G services in the UK after the auction, choosing to do so symbolically on 3/3/2003.

All five licences in 2000 contained an obligation on operators to achieve 80 per cent population coverage of 3G services, and ensure wide rollout of the new technology. However, the requirement fell between two stools. On the one hand, it turned out to be more challenging than expected for operators to meet, due to the move from stock market boom to bust and commercial incentives for slower 3G rollout. Some operators struggled and may have distorted their network rollout in order to meet the obligation. To use a pizza analogy, they may have provided 'thin and crispy' coverage that just met the defined requirements of the specific obligation, but offered less meaningful services to consumers than better quality 'deep pan' coverage. On the other hand, the 80 per cent reach was insufficient to assuage public concerns because it remained a long way from achieving even near-universal mobile coverage. The government later increased the requirement to 90 per cent population coverage in 2010, as part of a wider deal with the operators.

While the operators learned salutary lessons about avoiding overbidding in future, the learnings for the regulator were more fine-grained. The auction design provided bidders with an 'all or nothing' choice, as each was permitted to bid for only one pre-packaged licence in any round. The regulator drew the lesson that greater flexibility for bidders would be more important in later auctions when operators would already have larger spectrum portfolios and more diverse requirements to add new spectrum. Another regulatory lesson was the success of the competition measures, including spectrum reservation for a new entrant. Experience with the coverage requirements was more chequered, suggesting that it did not provide a simple solution to coverage concerns.

4G auction in 2013: surprises and complications

Various smaller auctions of less valuable spectrum occurred in intervening years, but the next high-stakes auction in the UK was not until 2013, when key bands for 4G services became available. One operator, EE, already had spectrum holdings suitable for early 4G – EE had been created in 2010 by a merger of previously separate operators, Orange and T-Mobile (formerly One-to-One). The other three remaining incumbents needed spectrum from the 2013 auction: these were now Vodafone, H3G, and Telefónica (which had bought BT's mobile operations).

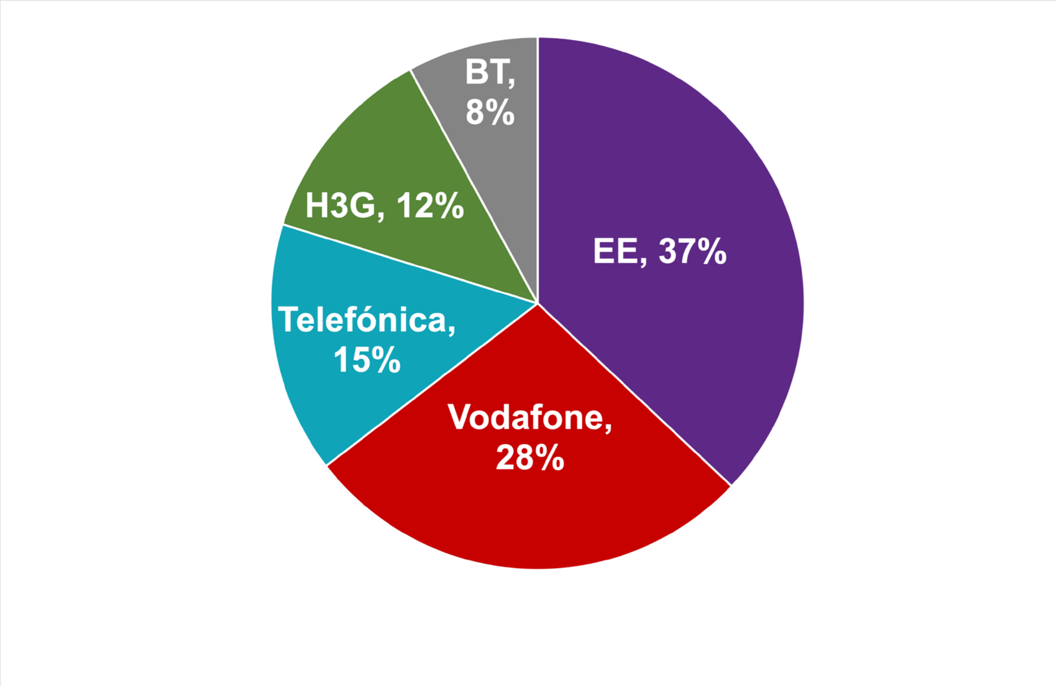
The regulator expected operators to have synergy values between the coverage and capacity spectrum in the auction. It also considered it was appropriate to use flexible spectrum reservation, a technique using 'spectrum floors' where auctions bids determined the particular frequencies to be reserved, instead of pre-specified set-aside spectrum. So Ofcom chose a complex and innovative CCA design, with 'bells and whistles' designed to fit the circumstances. These complications had a purpose but they worried operators. Some auction features worked, and others did not, but overall the auction managed 'not [to] topple over under the weight of its own complexities'.[16]

Most media reporting focused on the shortfall between the revenue of £2.4 billion and the pre-auction forecast of £3.5 billion made by the UK's independent Office of Budget Responsibility. Some commentary also made unrealistic comparisons to the £22.5 billion raised in 2000. However, it was appropriate that the 2013 auction was designed to maximise economic efficiency and public value rather than revenue. The bidding by operators was rational and reasonably competitive – for instance, the total prices were bid up to a billion pounds higher than the reserve prices of £1.4 billion. Three bidders without existing mobile spectrum joined the four incumbents as bidders. The biggest of these was BT, the dominant landline provider (and former state monopoly privatised in 1984). After spinning off its mobile arm a decade before in 2002, BT was once more interested in running mobile operations. The company was successful in the auction, perhaps surprisingly outbidding mobile incumbents for a portion of the capacity spectrum. The remaining lots were all won by incumbents, so that there were five winners in the auction. Two smaller operators (Hong Kong Telecom and MLL) participated, but were unsuccessful.

Some other aspects of the bidding and outcome were also unexpected. EE chose to bid much more aggressively at the margin for capacity spectrum than for coverage spectrum, and won a surprisingly large proportion of the capacity spectrum in the auction. By contrast, it won only a small amount of coverage spectrum, even though it had little pre-existing coverage spectrum in its portfolio. The choice of spectrum floor as the reserved spectrum was between a small amount of valuable coverage spectrum and a larger but less valuable block of capacity spectrum. Unexpectedly, the pattern of bids made by both H3G, the beneficiary of reservation in practice, and other bidders led to the higher-value coverage spectrum being determined as H3G's winning floor of reserved spectrum. Overall, the efficiency of the spectrum allocation that was achieved was hard to judge, because of conflicting indications. For example, the CCA auction format helpfully allowed bidders to express their synergy values, but it also made bidding more difficult for those operators with tight budget constraints.

The spectrum caps did their job but still permitted significant asymmetry in spectrum holdings – see Figure 2.5. There were subsequent ramifications, e.g. Telefónica, with only 15 per cent of total spectrum despite having more than 30 per cent of subscribers, became the largest winner of spectrum in the next auction in 2018.[17] The other main competition measure in 2013 of flexible reservation either for the smallest incumbent H3G or for a new entrant was contentious, both because it was interventionist and for the innovation of spectrum floors. Operators threatened to sue Ofcom in the courts but this was avoided, in part because the government reached a wider agreement with operators on a package of measures that included the 2010 increase in 3G obligation. Spectrum floors were subject to strategic bidding by H3G, but still seemed consistent with an efficient outcome (see Section 10.1 for details).

Figure 2.5. The UK operators' shares of spectrum after the 2013 auction



Source: Author from Ofom auction documents.

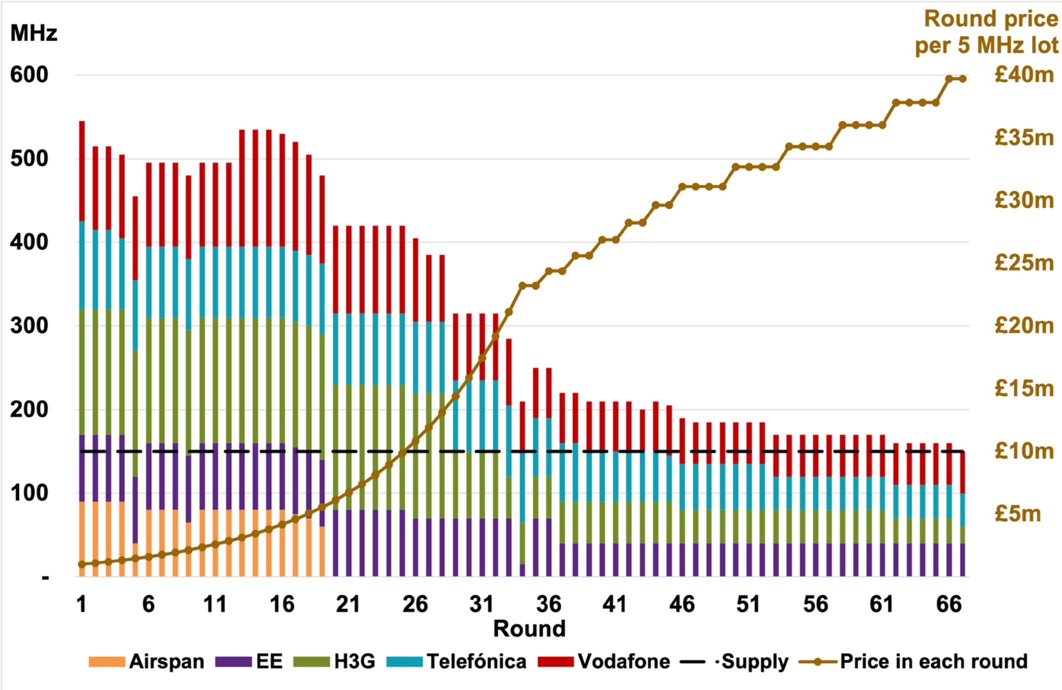
Turning to coverage requirements, an obligation requiring the operator to achieve 98 per cent indoor 4G coverage was applied to one licence, on the rationale that it would speed up rollout across the country and stimulate other operators to follow. The practical outcome was more complex, because that apparently simple headline masked substantial engineering complications in the detailed specification of the obligation. Telefónica won the obligation spectrum, but achieved lower coverage than intended on the ground, 95 per cent in 2018. Other operators achieved indoor coverage of 94, 89, and 88 per cent.[18]

Thus, as in 2000, competition measures were successful, and experience with the coverage obligation was messy. The complications in the auction design had mixed success, and the efficiency of the spectrum allocation was inconclusive. This outcome highlights that design innovations carry a two-sided risk. On the one hand, innovation can reap a reward from harnessing the auction to achieve desirable outcomes. But care is also needed to deploy 'heavy machinery' features only when they truly fit the circumstances.

PSSR auction in 2018: widely seen as successful

The spectrum in the 2018 auction was released by the Ministry of Defence after it shifted its relevant operations to alternative spectrum. One band in the auction was for 4G capacity, and another was prime 5G spectrum. In this case there were no strong synergies between the bands (which were both

Figure 2.6. Bids for the 5G spectrum band in the 2018 auction



Source: Author from Ofcom auction documents.

capacity spectrum), so Ofcom concluded that the complications of the CCA format were not needed. Instead a simpler design was used, the SMRA. The auction went very well, especially for 5G spectrum. Figure 2.6 shows the bids and prices in each of the 67 rounds of bidding for that band. There were initially five bidders, four incumbents (EE, H3G, Telefónica, and Vodafone) plus a potential entrant, Airspan. They all initially bid for large amounts of spectrum (totalling more than 500 MHz) at the reserve price of £1 million per 5 MHz lot. As demand was in excess of the available supply of 150 MHz, Ofcom increased the price in the next rounds. As prices continued to rise, the incumbents broadly maintained their demand until Airspan dropped out of the bidding at the higher price of £6.1 million per 5 MHz in round 20. The four incumbents then progressively reduced the number of lots they were bidding for as prices continued to rise until they all won spectrum blocks, generating £1.2 billion in revenues for the government (30 lots at the final price of nearly £40 million per lot). Simultaneously there was also bidding for the other band in the auction where Telefónica acquired the 4G spectrum to alleviate concerns about its network capacity constraints, adding another £0.2 billion to the revenue raised.

The most contentious aspect for this auction was Ofcom's imposition of spectrum caps, which led to pre-auction litigation and a 4-month delay before the all-clear to proceed. EE had been taken over by BT in 2016, combining their spectrum portfolios (but retaining EE as the brand name). One cap prevented EE from bidding for the 4G spectrum – to prevent it increasing its already large pre-existing holdings. The other cap limited EE's acquisitions of 5G spectrum. Although the latter did not turn out to be a binding constraint when the auction took place, EE's earlier legal appeal had claimed it was too restrictive. At the same time H3G mounted a legal appeal claiming the opposite, that the limit on EE was too lax. The regulator won both cases at the High Court and Court of Appeal, reinforcing the robustness of its competition analysis and decisions.

Once the auction started, it went smoothly, and the outcome satisfied the operators. It was also a good result for economic efficiency and promoting competition, and so was widely seen as successful. Telefónica won the 4G spectrum allowing it to provide better 4G services to its customers. All four operators launched their 5G services promptly enough in 2019. Because this auction awarded only capacity and not coverage spectrum, there were no coverage obligations in the spectrum licences awarded. The auction's success emphasised the benefits of a horses-for-courses approach to design choices, since the less complicated SMRA design was well suited to the prevailing conditions and met the regulator's objectives very effectively.

5G auction in 2021: short and sweet?

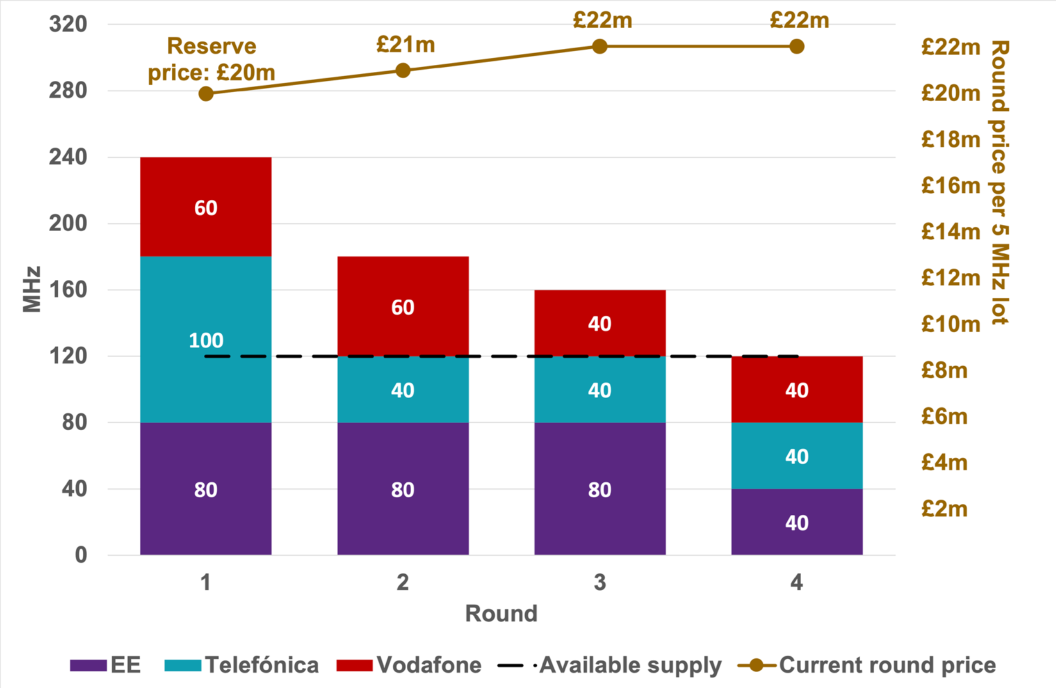
The next 5G auction awarded both coverage and capacity spectrum bands. It was due to happen in 2020 but was delayed by the Covid-19 pandemic, eventually taking place in 2021. It used a very similar SMRA design as in 2018. Bidding by the companies was starkly different, however, and far less competitive, lasting only 11 rounds for coverage spectrum and just 4 rounds of apparent tacit collusion for the capacity band as Figure 2.7 shows.

Only three incumbents bid for the 5G capacity band. H3G already held a large amount of 5G capacity spectrum and chose not to bid for more. The other firms initially bid for different amounts, but then took it in turns to reduce their demand to the 'focal' amount of 40 MHz each, in order to split the spectrum equally between them at a low price that was only just above the reserve level. The revenue generated by sales of this band was £0.5 billion (24 lots at £21–22 million per 5 MHz lot). The price was 45 per cent lower than for the very similar 5G spectrum sold in the 2018 auction. Such strategic bidding to win cheap spectrum is called 'market division', and one weakness of the SMRA format is that it is more vulnerable to such oligopolistic and concerted behaviour.

There was a little more competition in the bidding for the coverage band between all four operators (but no potential entrant participated in the 2021 auction). Vodafone dropped out in round 11, leaving the other three – EE, H3G, and Telefónica – to win equal amounts still at a relatively low price compared to benchmarks from European countries. Because the government had reached an agreement on coverage extension with operators the previous year (see Section 5.3), no coverage obligations were needed in the auction.

Assessing the success or failure of the 2021 auction differs depending on the view taken of the objectives. The desirability of the outcome was very questionable for those seeing revenue as an important objective, because total revenue was only £1.4 billion. That was the same as for the 2018 auction, but greater revenue might have been expected due to the valuable coverage spectrum included in the 2021 auction. However, revenue-raising was not part of the regulator's objectives. For efficient allocation and promoting downstream competition, which are usually more important than revenue, the auction had the advantage of being short and sweet. Despite the tacitly collusive bidding for the capacity band, the outcome plausibly achieved an economically efficient allocation, which was also desirable for vibrant downstream competition. This is because two operators that had less coverage spectrum (EE and H3G) increased their amounts, and all four of them achieved large holdings of 5G

Figure 2.7. Bids for the 5G capacity band in the 2021 auction



Source: Author from Ofcom auction documents.
Note: The numbers inside the column bars show the amount of each operator's MHz bid in that round, with only 120 MHz available.

capacity spectrum, thereby attaining strengthened spectrum portfolios to offer enhanced 5G services to consumers.

One key lesson from this experience for the regulator was that using the same design in different auctions provides no guarantee of similar bidding patterns. Both the 2018 and 2021 auctions used an SMRA design, but the contrast in operators' bidding behaviours was stark, as illustrated by the very large difference in bid patterns between Figures 2.6 and 2.7 for very similar 5G spectrum. The 2021 experience also emphasised that there are different ways to achieve desirable outcomes. Strong competition in the auction as in 2018 provides a far more secure route than self-interested operators exploiting weak bidding competition as in 2021. Ultimately, however, the competitiveness of auction bidding is only a means to the more important ends of promoting economic efficiency and downstream competition.

Overall, across all four auctions the UK experience has been mostly successful, especially through well-judged design decisions, learning over time, adjusting as conditions change, and active use of proportionate competition measures. Having provided in this chapter an introductory understanding of radio spectrum and auctions, and an overview of UK auctions, we are now in a position to explore the design decisions in greater detail. The next chapter starts by providing the conceptual underpinnings of auction design analysis.

Notes

1 A Hertz is defined as one wave per second. Other technical dimensions include transmission power in Watts and signal strength in decibels.

2 Based on Ofcom (2008b, figure 2.53).

3 Competition and Markets Authority (2015).

4 For more, see: Wikipedia 'GSM frequency bands', https://perma.cc/V58E-QV8L.

5 For historical accounts of spectrum management in the USA and arguments favouring auctions, see Kwerel and Felker (1985).

6 See Indian Premier League 'TATA IPL Auction – 2022', https://perma.cc/X6CK-PD9P.

7 See Financial Times 'Economist develops UK subsidy auction to save endangered turtle dove', 23 July 2021, https://www.ft.com/content/6bfbd5e2-10f9-4400-b4e1-258225e3ac0f

8 See Guinness World Records 'Most expensive painting sold at auction', https://perma.cc/AUC8-9GJC.

9 Nobel Prize (2020a).

10 See Amsterdam Tulip Museum 'Dutch Clock Auctions', https://perma.cc/D2UZ-FFX8.

11 Ashenfelter (1989).

12 The description here of the SMRA pricing rule as first-price or pay-as-bid reflects common colloquial practice, but is non-standard in the auction theory literature, especially given the functional similarity to second price. In the literature, a 'first-price auction' usually refers to sealed bids for a single unit; and a 'pay-as-bid auction' to sealed bids for multiple homogeneous goods, such as for Treasury bills, in which winners pay different (non-uniform) prices according to their bids (also known as a 'discriminatory auction').

13 A numerical example (using EE's real bids in the 2013 auction in £ million) is values of: 230 for one lot of 800 MHz; 697 for seven lots of 2.6 GHz; and 1,050 for the combined package (one lot of 800 MHz plus seven lots of 2.6 GHz) which was EE's winning bid in the auction. The synergy is 123, the excess of 1,050 over the sum of the values for the two smaller, single-band packages (see also Figure B1.5).

14 See BBC News 'Looking back at 3G auction in 2000', https://www.bbc.co.uk/news/av/technology-21522129.

15 From an interview with the Sunday Times – see French (2009, p.166).

16 Cave and Nicholls (2017, p.377).

17 Ofcom (2017, figure A1.17b).

18 Ofcom (2018c, figure 6).

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Note: means an open access publication.

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3. Market design, economic efficiency, and game theory for spectrum auctions

Summary

- Markets come in many shapes and sizes, including those created by conscious design to promote economic efficiency like spectrum auctions.
- Spectrum auctions show that markets can be a malleable instrument of public policy, in cases where well-considered design choices can harness incentives of self-interest, such as companies seeking profits, for socially desirable outcomes.
- Features that can make a market successful include: a clearinghouse; effective competition; sound incentives; institutions with good reputations; transparency, simplicity, and flexibility for timely decisions by participants; and respecting social and cultural constraints of fairness and public acceptability.
- A valuable analytical approach when considering intervention in markets is to assess the existence and sources of market failure.
- The tools of game theory and auction theory contribute greatly to the practical design of spectrum auctions. There is a symbiotic relationship, because the theory also develops by learning from practical challenges and bidding experiences.

There are many different types of markets, operating in a wide variety of contexts. Spectrum auctions are one particular type of market. Their existence and operation are due to conscious 'market design'. The rules chosen for them and the market infrastructure designed are intended to achieve specified objectives. The first section of this chapter explains the perspective of market design and one of its key objectives, economic efficiency. This sets the specific market of a spectrum auction in a broader context (and indicates features that are examined in greater depth in Part II). The second section provides a non-technical introduction to auction theory which supports practical market design, building on the tools of game theory. The third section shows the important role that experts play in spectrum auction design in a mutually beneficial relationship between theory and practical implementation,

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How to cite this book chapter:

Myers, Geoffrey (2023) *Spectrum Auctions: Designing markets to benefit the public, industry and the economy*, London: LSE Press, pp. 35–52. https://doi.org/10.31389/lsepress.spa.c.

each learning from the other. The final section provides some wider lessons for public policy that can be taken from the experience of spectrum auctions as a market mechanism to promote the public interest.

3.1 Market design and economic efficiency

The understanding of how and why markets can be successful, or go wrong, is greatly enriched by the field of study of market design. In essence, market design opens the 'black box' of how markets work. It grew out of game theory, a mathematical field in economics that illuminates strategic behaviour and can be described as the 'formal study of conflict and cooperation'.[1] Although the theory can be abstract and esoteric, the applied side of market design is intensely practical as it seeks to develop workable market solutions to real-world challenges. A high-level insight from market design is that 'a free market is a market with rules and institutions that let it operate freely'.[2] In this fundamental sense, the operation of markets is underpinned by regulation (broadly defined) – the role and nature of regulation are considered in Chapter 4.[3] Examples of designed markets other than spectrum auctions include wholesale electricity, tradeable pollution permits, online advertising, labour market clearing-houses for newly qualified doctors and hospitals, procedures to match students to schools or colleges, and centralised systems for the allocation of human organs from donors to patients.[4]

When markets are designed by public authorities, one objective is usually to achieve economically efficient outcomes, explained in the following subsection. Broader objectives can also be very important – these are covered in Chapter 4. The second subsection uses insights from market design to set out features that facilitate a healthy market which is successful in achieving economic efficiency (and other relevant objectives). However, markets can and do go wrong, so the third subsection characterises sources of market failure. To round out the section, the last subsection indicates the potential offered by the market design perspective.

Economic efficiency (social value)

The concept of economic efficiency has several dimensions:

- Allocative efficiency means that scarce resources (like parts of the radio spectrum) are allocated to those users who will best deploy them to maximise the total outputs valued by economic agents.[5]
- Productive efficiency involves minimising the costs and resource inputs used to supply or achieve a given output, such as spectral efficiency in providing mobile data services.
- Dynamic efficiency involves maximising valuable investment and innovation, such as revolutionary new mobile services which change the way we live and work, as has already occurred and may happen again with 5G and future technologies.[6]

Together these types of efficiency specify the maximum social value focused on by economists. It can be described as the overall size of the economic 'cake' – the extent to which agents' preferences can be satisfied, given resource and technological limitations. Two key underlying concepts in welfare economics are widely used. So-called Pareto efficiency is achieved if no-one can be made better off without someone else being worse off.[7] It is a foundational concept, but restrictive as a criterion for ranking different allocations of society's resources to decide which is more or less 'efficient', because many changes in allocation involve losers as well as gainers. The compensation principle significantly expands the applicability of welfare economics.[8] It holds that economic efficiency is increased if the agents (whether producers or consumers) that are made better off *could* compensate the losers by a sufficient amount so that all would be at least as well off as before. But it is not essential that such compensation actually occurs.

A distinction between the size of the cake (economic efficiency) and the 'slices' obtained by different agents (distributional issues) is analytically useful. But there are value judgements involved in suggesting that a larger cake is necessarily better than a smaller one. Some people might consider that a Pareto change, increasing economic efficiency, from a large increase in wealth to billionaires that magnified inequality would not truly be an overall welfare improvement, even if others' welfare stayed the same or increased in absolute terms. The compensation principle involves stronger value judgements, given that it relies just on the potential for compensation, whether or not it actually occurs. Therefore, it would, for example, 'approve a change that makes the wealthiest man in society richer by $1 billion, while making each of the million poorest people worse off by $999. This is a judgement that many people would reject as wrong or immoral'.[9] Such considerations of fairness can lead public policy choices to go beyond potential compensation and actually recompense those who are worse off. A spectrum example is incumbent users for television broadcasting, who were cleared from a band for re-award to mobile operators, receiving financial payments to cover their costs (Section 6.1).

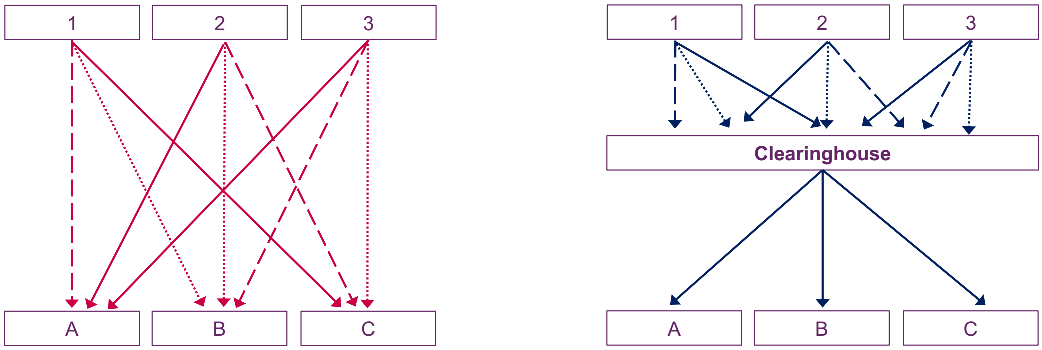
Features of successful markets

The tools of market design can be used to identify features of a well-functioning market, like a spectrum auction. There is no simple recipe to make sure a market succeeds, but market design experts have established how a range of features can generally contribute, drawing on theoretical insights and practical experience.[10] Markets involve rules and infrastructure. The rules govern how the market works, and the term 'infrastructure' is used broadly, meaning not just physical or virtual infrastructure like an exchange or software platform but also institutions that help to run the market. The features outlined in this subsection are explored in later chapters in Part II in their practical application in spectrum auctions.

A centralised *clearinghouse* can sometimes assist a market to work well, as in matching markets. Figure 3.1 provides a simple illustration of the difference with and without a clearinghouse, showing three participants or objects on each side of the market. The unbroken, dashed, and dotted arrows from the top signify an order or strength of preference of participants, labelled 1, 2, and 3 for the objects shown as A, B, and C. These could be students to be matched to schools, trainee doctors matched to hospitals, or mobile operators seeking to acquire different spectrum blocks.[11]

The coordination provided by a clearinghouse can bring benefits like simplifying choices or encouraging participation to improve the thickness (volume) of transactions with enough buyers and sellers. This can allow more *competition* and achieve an improved allocation. Participants transacting through a clearinghouse is not always the right answer, but it can offer additional possibilities. An example is comparing a series of bilateral negotiations for trades of spectrum licences (illustrated by the left-hand side of Figure 3.1) against a multilateral spectrum auction with the regulator as the clearinghouse (on the right-hand side). The auction can reduce transactions costs, assist coordination, and

Figure 3.1. Simplified illustration of a bilateral uncoordinated process compared to a multilateral coordinated process with a clearinghouse



Source: Auhor.

improve incentives. There was a period of time in the USA when spectrum licences were allocated by lottery relying on subsequent bilateral trading to get the licences into the hands of the highest-value operators. Spectrum auctions have brought allocation improvements, as well as other efficiencies such as reduced rent-seeking.[12] Command-and-control administrative allocation of licences involves the regulator as a clearinghouse, but without the vital dispersed knowledge of participants powerfully coordinated through a market mechanism.[13] For example, imagine the clearinghouse on the right-hand side of Figure 3.1 making the allocation decisions for items A, B, and C in the bottom half without reliable access to the information on preferences of operators 1, 2, and 3 in the top half.[14]

The rules and institutions of the market affect the *incentives* of participants for straightforward over strategic behaviour. The importance of incentives is brought out in the next section when describing game theory. In addition, bidder incentives in spectrum auctions are examined in in Part II, especially in Chapter 8 which builds on insights from auction theory.

Another feature is to reduce 'congestion' for a safe environment to engage in *timely* transactions. Timeliness has different aspects, including when a participant is asked to make decisions, their sequencing, and how much time it is given. Section 6.2 considers some aspects of timeliness (licence duration and when to hold an auction), and Section 11.2 analyses congestion in terms of the pace of the auction.

The behaviour and reputation of *institutions* influences whether participants see the regulator as reliable, neutral, and trustworthy to run the market fairly. Operational issues are also relevant, such as secure systems for bidding and protection of confidential data. Section 7.6 examines how attributes and actions of the regulator can affect the trust of market participants.

Transparency, flexibility, and simplicity assist market participants to make informed decisions. Chapter 8 uses these important considerations to structure the detailed analysis of trade-offs in spectrum auction design. For example, the final prices in the CCA, second prices based on the highest-losing bids, are less transparent and simple than in the SMRA, but they are more flexible (such as reflecting synergy values for complements).

Success also depends on respecting constraints set by society – an example is that monetary transactions in some cases are considered ethically *repugnant*. Markets can only work if they operate consistently with public values (which can modify over time, but for present purposes they are taken as given). An elegant theory of efficient allocation of kidney organs based on monetary payments could be developed, but it would not work in practice and could not be implemented effectively if public values reject the fundamental financial mechanism being used in the allocation. This still leaves plenty of scope for market design solutions using non-monetary transactions to improve the efficiency of the allocation, such as rules and infrastructure of medical exchanges acting as a clearinghouse.

Beyond repugnance, there are broader matters of *fairness*, including distributional effects and political acceptability. In the world of radio spectrum, there are a few types of spectrum user for whom the use of markets and financial payments is more contentious, such as safety-of-life applications of the emergency services, or wireless microphones and cameras in theatres. But the focus of this book is on spectrum markets for cellular mobile services, for which markets and monetary transactions are generally deemed socially acceptable or even expected. Nevertheless, the fairness of spectrum auctions is still important, as considered in the reputational issues in Section 7.6, or in Section 3.2 for fair prices from the second-price rule of the CCA format.

Sources of market failure

Many of the considerations can be formulated as features of well-functioning markets or their absence, market failures – see Figure 3.2. The market failure framework provides a powerful analytical tool to diagnose whether and why markets are performing well. Identifying the source of a problem is at the heart of prescribing the effective 'medicine'. Different sources of market failure are relevant to analyse a range of issues. Spillovers of broader social benefits may be insufficiently reflected in market

Figure 3.2. Reasons why a market does or does not work well including sources of market failure

Features of well-functioning market	Source of market failure
Spillover effects on those not directly involved are taken into account	Externalities
Rights of ownership or access enable transactions to occur effectively	No or unclear property rights
Transactions costs are not too large relative to the gains from exchange	High transactions costs
Institutional arrangements promote trust between transacting parties	Absent or unreliable institutions and lack of trustworthiness
Incentives to use resources efficiently	Distorted or missing signals, such as prices (where they are not considered repugnant)
Information flows smoothly between market participants	Asymmetric information
Competition is fostered	Weak competition, such as companies with market power
Market participants take unbiased, well-informed decisions	Behavioural biases[15]

Source: Author, drawing in particular on McMillan (2002).

outcomes for mobile coverage (Section 5.3). Externalities of radio signals interfering with each other provides a rationale for spectrum licensing to define property rights, and transactions costs can be a barrier to efficiency-enhancing spectrum licence trades (Section 6.2). The reliability of the regulator as an institution can affect the performance of the market (Section 7.6). Price discovery and asymmetric information are fundamental challenges in auction design (Chapters 7 and 8). Competition measures are often imposed in the auction to avoid weak competition in downstream markets (Chapter 9). Behavioural biases of fear of losing or overconfidence may have contributed to overbidding in the UK's 3G auction in 2000 (Sections 2.3 and 11.1, and Annex A2).

The potential of market design

It is far from accurate to suggest that every problem has a market solution. As well as markets in some contexts being prone to systematic failure, there are also values at stake.[16] Some economists consider their analysis is 'value-free', but leaving aside the questionable accuracy of such a proposition within the field of economics, the use of markets is not perceived more generally to be value-neutral. Market design theorists and practitioners interested in developing solutions to real-world public policy problems are eclectic, not dogmatic. They grapple with challenges of broader social considerations beyond the narrower values reflected in economic efficiency, such as recognising that monetary transactions are publicly unacceptable in some cases. They have shown there are more problems that markets can assist in addressing than non-specialists might think. The contributions to matching problems like human organ donation are noteworthy examples. One of the high-level insights is that markets can come in all shapes and sizes, and they can often be harnessed to serve the public interest. The rest of this book is the story of what has been achieved in the context of spectrum auctions, especially using evidence from the UK, and their future potential.

3.2 Introduction to game theory and auction theory

Modern microeconomics has developed to place greater reliance on game theory in explaining the behaviour of rational actors and especially their strategies in complex situations. This section sets out a high-level, non-technical introduction to fundamental features of game theory as utilised in auction theory. Auction theory is a branch of market design, whose implications are drawn on when analysing design choices in later chapters, doing so starting from a practitioner perspective. The confluence of theory and practice was recognised in the 2020 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel, awarded to Professors Paul Milgrom and Robert Wilson 'for improvements to auction theory and inventions of new auction formats'. The citation noted that their 'theoretical discoveries have improved auctions in practice' and referred prominently to spectrum auctions, highlighting it as a key area of practical application and stimulus for innovative developments [emphasis added]:

> This year's Laureates, Paul Milgrom and Robert Wilson, have studied how auctions work. They have also used their insights to design new auction formats for goods and services that are difficult to sell in a traditional way, such as *radio frequencies*. Their discoveries have benefitted sellers, buyers and taxpayers around the world.[17]

Figure 3.3. Illustrative payoff matrix in the prisoner's dilemma game

	Aardvark	
Beaver	Stay silent	Confess
Stay silent	Aardvark: −0.5; Beaver: −0.5	Aardvark: 0; Beaver: −5
Confess	Aardvark: −5; Beaver: 0	Aardvark: −2; Beaver: −2

Source: Author from Rapoport (1987).

Game theory, in essence, is an analytical tool to study strategic interactions of conflict and cooperation between 'players' where there are interdependent outcomes. For illustration, the players could be called Aardvark and Beaver. Aardvark's best choice depends not only what it decides, but on Beaver's action as well, in situations where they may not have the same information and only imperfectly observe each other's actions.[18] Incentives and outcomes then depend on the environment, motivations, and expected payoffs.

A well-known example of a game is the prisoner's dilemma.[19] Two prisoners suspected of burglary are held captive separately with no means of communicating. Each has two options: to confess, blaming the other prisoner; or to stay silent. If Aardvark confesses but Beaver does not, it is set free but Beaver is convicted of burglary and faces a prison sentence of five years, and vice versa. If both confess, they share the blame for two years each in prison. If both stay silent, they are convicted of the lesser crime of possessing stolen goods with only six months in prison. The payoffs to both prisoners are represented in Figure 3.3 where the negative numbers indicate the number of years in prison, in red for Aardvark and in green for Beaver.

The best combined outcome for the prisoners is if both stay silent and face a short prison sentence. However, the game theory analysis shows instead that both have a dominant incentive to confess, so the confess/confess outcome with two years in prison forms the unique equilibrium. Aardvark reasons that it is better off confessing, whatever action Beaver chooses:

- If Beaver stays silent, Aardvark's possible outcomes are shown in red in the first row in Figure 3.3 and it prefers to confess (payoff of 0, set free, instead of -0.5, half a year in prison).
- If Beaver confesses, Aardvark is again better off by confessing, given the choice of outcomes in the second row (payoff of -2 instead of -5, two not five years in prison).

Beaver's reasoning is the same because the payoff matrix is symmetric. So the prisoners face a worse outcome by confessing (two years in prison) than if both stayed silent (six months). The prisoner's dilemma game therefore shows the importance of players' incentives. A version of the game with many players models the 'tragedy of the commons', overuse of resources like spectrum due to individual incentives leading to an undesirable collective outcome.[20] These insights are directly relevant to spectrum licensing (Section 6.2). Simple game and spectrum auction examples can also illustrate key game theory concepts.

There are two basic types of game, *cooperative* and *non-cooperative*, and the prisoner's dilemma is an example of the latter. Non-cooperative games examine decisions of individual players, whereas the unit of analysis in cooperative games is groups of players who can make binding agreements to form different coalitions. A cooperative game version of the prisoner's dilemma would be different. If the prisoners could make a binding agreement with each other, they could agree to stay silent and be better off. The agreement would have to be binding, however, as otherwise the incentives of the non-cooperative version would come to the fore and both would have an incentive to cheat on the deal. In non-cooperative games there are only 'agreements' between players if they are self-reinforcing, if each is better off agreeing than disagreeing so that no player has an incentive to deviate (which makes the confess/confess outcome the equilibrium of the non-cooperative prisoner's dilemma game).

Cooperative and non-cooperative game theory are broadly aligned with two branches of market design: *matching* theory and *auction* theory. Both involve marketplaces, for matching without monetary transactions, and in auctions with financial bids. Insights of matching theory are used in a range of allocation systems, such as assigning students to schools, newly qualified doctors to hospitals, or kidney donors to patients.[21] Implications of auction theory are crucial to designing the rules of spectrum auctions.

One element of a game is a specification of each player's available strategic choices and their associated payoffs, as shown in Figure 3.3 for the prisoner's dilemma. To be an accurate representation, the choices modelled in the game have to be complete or at least not omit significant available actions (which is not straightforward in more strategically complex environments). The payoffs perceived by the players depend on their motivations and what they value. For instance, social norms about informing on fellow prisoners could change the relative payoffs shown in Figure 3.3 to make confessing a far more costly choice. A company bidding in a spectrum auction usually cares about profit on the items won (their value to the firm less the prices paid). But Chapters 8 and 9 also consider other influences on the payoff from strategic bidding, such as forcing rivals to pay higher auction prices (so-called 'price driving') or denying spectrum to a rival to weaken downstream competition ('strategic investment').

Another element is the structure of the game, involving *simultaneous* or *sequential* decisions by players. There are simultaneous decisions in the prisoner's dilemma in the sense that Aardvark does not know Beaver's action when it has to make its decision, and vice versa. Similarly, a sealed-bid spectrum auction is a simultaneous game between bidders. An example of a sequential game is auction design. The regulator sets the auction rules in the first stage of the game, which are then known to the bidders when they choose their bids in the second stage. To set the rules in the first stage to achieve desirable outcomes, the regulator has to understand how bidders will respond in the second stage to different choices of rules. This set-up is used in auction theory models to yield insights that are explored in Chapters 7 and 8. Another example is that the outcome of the auction affects the strength of downstream retail competition between mobile operators. The competition assessment set out in Chapter 9 requires the regulator to understand how different auction outcomes would impact downstream competition and the associated incentives for strategic investment in the auction, in order to make the right prior decisions about competition measures to impose as auction rules.

A further structural feature is whether the game is *one-shot* or *repeated*. The prisoner's dilemma is a one-shot game since it is played only once by Aardvark and Beaver.[22] A sealed-bid auction is a one-shot game, whereas SMRA and CCA as multiple-round auctions are more like repeated games, where bidders receive information on what happened at the end of each round and (within defined limits) can change their choices in the next round accordingly. The sequence of spectrum auctions over time in a country (e.g. 3G, 4G, and 5G) can also be seen as a repeated game, which involve the same or significant overlap in players. Or there can be a sequence of auctions across countries with overlap in bidders because many mobile operators are multinational. In this sense, any one spectrum auction can be viewed as a game within a bigger game, increasing the strategic complexity of the environment since players' actions could be designed to affect future or overseas auctions as well as the current one. Sections 2.3 and Annex A informally present the sequence of high-stakes UK auctions as games within a bigger game of learning over time by bidders and the regulator. Auction design is a process of constant change, involving evolutionary and more radical changes affected by prior experiences. A further example is the repeated game for universal mobile coverage (informally) examined in Section 5.3, with the same players (the government, the regulator, mobile operators, and the public) periodically interacting over time, resulting in sporadic action to enhance coverage. But there is always another stage of the game, with more to be done to extend coverage or bring it up to date to the latest technology.

The information conditions of the game are important, giving a precise formulation of who knows what and when. Private information is only known by each player for itself, such as each bidder's value of spectrum in the auction. Rivals often estimate each others' values to inform their bid strategies. Since mobile operators know each other well, in some cases their estimates can be fairly accurate, assisting strategic bidding such as price driving, by knowing how high to push up the price. But private information means that estimates can be wrong, such as a price-driving bidder misjudging and ending up paying for spectrum that it does not want. Common knowledge is information known to all players (and everyone knows that everyone knows it), such as published by the regulator as part of the 'information policy' before the auction, or revealed to all bidders during the auction. As explained in Part II, the regulator's choice of information policy affects both incentives for strategic bidding and the economic efficiency of the outcomes.

Outcomes of games are modelled using solution concepts. The 'Nash equilibrium' of self-reinforcing, mutually consistent strategies is commonly used to solve non-cooperative games (named after the mathematician John Nash, who was depicted in the popular film *A Beautiful Mind*). Each player does its best to achieve its objectives, taking as given the choice of other players. For example, the logic of the Nash equilibrium was used when describing the reasons for the confess/confess outcome of the prisoner's dilemma game. In cooperative games the solution concept is usually about stability. For example, the 'core' is the set of undominated outcomes 'for which no "blocking coalitions" can form and produce an outcome that its members prefer'.[23] The core is specifically used in the (complex) pricing rule of CCA spectrum auctions for its stability and associated fairness properties. It ensures that no losing bidder (as expressed through its bids) was willing to pay more than the auction price for spectrum won by others (see Annex B2 for further explanation).

Cooperative and non-cooperative games are now considered complementary because there is always a bigger game outside the market designer's control:

> For parts of the game that we're designing, we use 'noncooperative' strategic models to precisely specify actions available to players. For parts of the game that we don't have complete control over, we use 'cooperative' coalitional models to tell us something about the incentives that agents and coalitions of agents may have to circumvent the rules.[24]

For example, core pricing should mean that bidders do not have an incentive to do deals outside the auction to change the allocation of spectrum. Also, Section 5.3 tells the story of UK mobile operators disliking the regulator's proposed CCA design to incorporate coverage obligations into the 2021 auction (a non-cooperative game). Their response can be seen as forming a coalition (cooperative game) to negotiate a coverage deal with the government, which led to a binding agreement. The coverage obligations were therefore superseded and removed from the auction, which led to the auction format being changed to SMRA which the operators preferred. In addition, although spectrum auctions are usually analysed as non-cooperative games, they can be characterised as 'heterogeneous matching with prices and complementary goods', emphasising the relationship to cooperative games and matching theory.[25] The matching is between mobile operators and spectrum blocks. It is heterogeneous, because operators have differing demands and spectrum bands vary in their characteristics; and complementary goods are involved if there are synergies between items in the auction.

Game theory is relevant not only to auction design choices, but also to the analysis of decision-making roles and processes. For example, Section 4.2 considers incentives to coordinate between professional skill groups within a regulator. Simple games can illuminate the basic incentive structure for players to cooperate with each other, such as the prisoner's dilemma being a case of individual incentives not to coordinate.[26] Another simple example with different incentive properties is the assurance game where cooperation is desirable but risky.[27]

3.3 Using expertise in spectrum auction design

The work of auction theory experts and practitioners is intertwined for designing spectrum auctions, because they present a challenge to distil complex analysis into practical rules attuned to specific circumstances. Designing spectrum auctions, drawing on or inspired by auction theory, involves public policy choices that combine practical appreciation of bidder behaviour, commercial realities, and technological opportunities with deep understanding of the implications of different auction formats and their associated rules. As may become obvious to readers of Part II, such as the in-depth discussion of auction design choices in Chapters 7 and 8, a significant degree of expertise is valuable for well-informed judgements. A notable example of an external expert is one of the recipients of the Nobel Memorial Prize in 2020, Paul Milgrom, who was instrumental in innovative designs for the Federal Communications Commission (FCC) in the USA in 1994 and in 2016–17 (the so-called incentive auction). He also advised Ofcom on the UK's 2018 and 2021 auctions. In addition, internal experts are important for practical decision-making, showing why effective choices depend on embedding technocratic expertise in processes that include wider public policy concerns. Chapter 5 explores different aspects of the role of experts in policymaking.

Governments have used auctions since Roman times, but the first spectrum auctions took place in New Zealand and Australia in 1989–90 and 1993.[28] They were somewhat troubled with bidder default problems in Australia and questions in New Zealand about allocation efficiency and low revenue (85 per cent less than forecast).[29] For example, there was adverse publicity when some of the licences sold at rock-bottom prices set on the basis of the highest losing bid (second price). In a few cases, prices were less than 0.1 per cent of the winning bid (for example, a price of NZ$6 compared to the winning bid of NZ$100,000, or NZ$5,000 price vs bid of NZ$7 million).[30] In contrast, the 1994 auction in the USA was widely regarded as a great success. Some commentators stressed the importance of experiments and simulations, but one of the key things different about the design of this auction was heavy involvement from academia of auction theorists: 'The story of how the spectrum auction was designed is a case study in the policy application of economic theory'.[31]

A two-way feedback loop between auction theory and practice has, therefore, been in play since the USA's 1994 auction. The auction format proposed by the theorists and adopted by the FCC did not come from the textbook, but was newly developed for the challenges of that auction.[32] Paul Milgrom, one of the developers of what came to be known as the SMRA, described how he was inspired by practical observation of silent charity auctions, where multiple items are offered simultaneously within a fixed time window, and bidders write their names and bids on a sheet of paper for each item and displace the current provisional winner by making a higher bid.[33] The influence was to learn from both successful attributes and weaknesses. Like silent charity auctions, the SMRA provides clarity on which bidders are winning at any point in the auction through a 'standing high bid' mechanism. The auction is simultaneous, with multiple items being awarded in the same process, allowing bidders to switch between them, and prices to rise if there is excess demand. A problem in silent auctions is that a bidder can swoop in at the last minute, leaving no time for other bidders to respond ('bid sniping'), which has also been observed in internet auctions such as eBay.[34] One mitigating feature introduced in the SMRA is that bidders always have an opportunity to bid back if their standing high bids are displaced (because the closing rule is that the auction ends only if there are no new bids in any category). Another mitigation is an 'activity rule' that prevents a bidder from increasing the amount of spectrum it bids for as prices rise (consistent with straightforward bidding) to prevent a firm from hiding its demand and engaging in a 'snake-in-the-grass' strategy like bid sniping.[35]

Therefore, since the early days, auction theory experts have played a significant role in practical design of spectrum auctions, bridging the 'ivory tower' and the messy real world. Auction theory cannot be applied mechanically because realistic conditions of spectrum auctions are usually more complicated than the theoretical models with their inevitably simplified or stylised assumptions for 'useful idealisations' as they seek to capture insights or particular aspects of reality.[36] Models can be informative for the practitioner, focusing on one type of effect by assuming others are not present using a 'well-chosen simplification', whereas the real world is sprawling and multifaceted, and regulators have limited ability to restrict the auction environment.[37] In this sense, 'each economic model is like a partial map that illuminates a fragment of the terrain'.[38]

The specification of motivations of participants in models may be wrong or incomplete (whether for bidders or regulators). For example, bidders may care not only about profit from the auction, as they could be playing a bigger game due to interactions with wider policy questions or relationships. Or they could view it as a repeated game with future auctions. The bid team could have their own objectives which are not fully aligned with the company's owners.[39] Or the firm could be subject to behavioural biases.[40] Another example of limitations of auction theory is that it is usually based on solving for an equilibrium of the relevant game, whereas 'in practice, participants do not always play according to equilibrium'.[41]

The theory can still greatly advance understanding by enabling experts, alongside practical experience, experimentation, and computation, to develop intuition that can illuminate design implications of specific effects which are part of, but not the complete, picture.[42] Experts can assist in understanding how different rules and parts of the auction interact with each other. Perhaps most importantly they can provide insights into which details or trade-offs matter the most, and which are of lesser importance. The regulator's auction design decisions can be made by combining these insights with practical know-how.[43] One of the Nobel Laureates in 2020, Robert Wilson, noted the particular importance of the practitioner point of view in market design:

> So concepts from game theory have been useful guides in efforts to improve the performance of trading platforms. But scholarly theorizing is minor compared to hands-on engineering using knowledge of an industry's technology and practices, and familiarity with participants' concerns is necessary if one is to help them obtain better outcomes overall.[44]

The interaction is two-way as practical experience and the complex reality highlight gaps in the theory, often leading to subsequent scholarly developments providing new, richer insights. The practical use of the SMRA in 1994 spurred the theorists to develop a better understanding of the attributes of this auction format.[45] Although this book refers for simplicity to 'the SMRA', it is in fact a family of evolving auction designs. Various modifications have been developed to mitigate previously unforeseen behaviour by bidders. An example is to limit 'jump bids', where bidders increase their bid amounts by more than a single bid increment, which can provide signals to other bidders. Another development is to incorporate new theoretical insights such as 'generic lots' to group similar but not identical frequencies for a faster, more efficient bidding process (Section 7.5). In response to limitations of the SMRA, theorists have also invented new auction designs. A difficulty for bidders in the SMRA format is 'aggregation risk' where different spectrum lots in the auction are complements so that a bidder can be left stranded, winning one lot but not the other needed to realise the synergies. Allowing package bids that win or lose in their entirety removes aggregation risk for bidders. Theorists (again including Paul Milgrom) developed the 'clock-proxy auction' with package bidding, which in modified form was then put into practice by regulators.[46] The UK regulator was an early adopter of the resulting format which came to be known as the CCA.[47] Another example of new formats is the descending clock auction developed (yet again by Paul Milgrom and colleagues) to address the hugely complex challenges of buying spectrum from TV broadcasters in the USA's 2016–17 incentive auction.[48] The symbiotic fields of academic study and practical implementation are therefore constantly evolving, seeking both evolutionary improvements and more innovative, revolutionary step-changes.[49]

3.4 Wider lessons for public policy

A number of broader lessons for public policy can be taken from the case of spectrum auctions as an important example of market design in practice, such as the UK experience outlined in Section 2.3. Spectrum auctions exemplify the value of well-judged use of *expertise* because of the vivid examples of successes and failures. The UK's largely successful auctions benefitted from the advice of external experts with deep understanding of auction theory and practice (Ken Binmore and Paul Klemperer in 2000, Peter Cramton in 2013, and Paul Milgrom in 2018 and 2021) in addition to well-informed economic consultants and internal experts.[50] Failures can sometimes be a product of circumstances. But earlier chapters highlighted undesirable examples in other countries that were avoidable due to high reserve prices that left spectrum unsold in Australia and India, faulty design choices that led to questionable spectrum allocation in New Zealand, or agonisingly slow auctions in Finland and Portugal. The consequences of insufficient use of expertise were losses suffered by the public in delayed or lower-quality services.

Another lesson is the importance of *learning* from ongoing processes by both public and private participants. We can see any auction as a game within the wider game of a series of auctions over time, involving the same or overlapping players. The UK experience shows how learnings from one auction were applied to later occurrences. This happened in a nuanced way for the regulator (such as changing from less flexibility for bidders in 2000 to more granularity in later auctions). Companies bidding in the auctions learned starker lessons from overbidding at the height of a telecommunications stock market boom in 2000. They avoided repeating the costly mistake (estimated at £10 billion by one of the bidders, Peter Bonfield, BT's chief executive at the time).

More fundamentally, the theory and practice of market design also show that we can see 'the market' as far from immutable, because markets can operate in so many different ways. We can instead recognise the potential of markets as a *malleable* policy instrument. They can be shaped and designed for public purposes in cases where it is feasible to harness self-interest, such as companies' profit incentives, to yield socially desirable outcomes. For example, careful design of spectrum auctions has promoted efficient allocation and strong retail competition, and incorporated obligations for enhanced mobile coverage to benefit the public as consumers and as citizens. As a by-product, taxpayers have also gained from the scale of auction receipts for the government. In addition, there have been gains to industry through access to valuable scarce resources, and to the economy through improved mobile infrastructure. However, a simplistic read-across of success in one policy area to other contexts should be avoided. The requirement instead is for experts as skilled practitioners to wield precision tools, scalpels not sledgehammers, identifying the right surgery after careful diagnosis of the source of past problems and the future potential.

Notes

1 Turocy and von Stengel (2001, p.4).

2 Roth (2012).

3 Koop and Lodge (2017).

4 See Chen et al (2021) for a survey of market design research in online auctions, spectrum auctions, financial markets, online feedback systems, and matching in education and labour markets.

5 Reiter (2008).

6 A universally agreed definition of dynamic efficiency is lacking. In one view, it is less distinctive – for example, process innovation for cost reduction can be related to productive efficiency, and product innovation to allocative efficiency. However, another view regards dynamic efficiency as a transformational contrast to 'static' allocative and productive efficiency. For a regulatory agenda about dynamic efficiency promoting investment in 5G through access to spectrum, see EU (2021).

7 Lockwood (2008).

8 Chipman (2008).

9 Feldman (2008, p.7).

10 Roth (2007), and Kominers, Teytelboym, and Crawford (2017).

11 A simplification in Figure 3.1 is the expression of preferences by agents shown on one side at the top (1, 2, and 3), but not the other side (A, B, and C). Preferences of both are relevant in a range of situations, such as doctors and hospitals, or marriage partners.

12 FCC (1997, section III).

[13] Hayek (1945).

[14] Another example is the USA's incentive auction in 2016–17, when the regulator, the Federal Communications Commission, was the clearinghouse linking broadcasters selling their spectrum rights to mobile operators buying them: 'For the incentive auction, however, finding a good plan (including how many channels to clear, which stations to retune, and how to retune them in a way that satisfies millions of interference constraints) and the clearing prices while still enforcing all of the interference constraints is a computationally hard problem, which requires a coordinated solution involving very many parties. Thus, a central authority like the FCC has an indispensable coordinating role.' – Leyton-Brown, Milgrom and Segal (2017, p.7205).

[15] For a critique of treating consumers' decisions as biases or mistakes instead of context-dependent choices, see Sugden (2022, section 7).

[16] Values and norms can also be changed by use of markets – see Michael Sandel's 2009 Reith lecture 'Markets and Morals' https://www.bbc.co.uk/programmes/b00kt7sh.

[17] Nobel Prize (2020c).

[18] Roth and Wilson (2019, p.123).

[19] Rapoport (1987).

[20] Ostrom (2008).

[21] See Alvin Roth's 2017 Morishima Lecture at LSE, 'Marketplaces and Market Design' https://www.youtube.com/watch?v=D5qCvMqqwC8.

[22] The prisoner's dilemma can also be modelled in theory as a repeated game in which the prisoners both choosing to stay silent can emerge as an equilibrium. There have been many experiments showing this outcome, especially with more plays of the game – see Rapoport (1987).

[23] Roth and Wilson (2019, p.124).

[24] Roth and Wilson (2019, p.127).

[25] Milgrom and Vogt (2021, p.29).

[26] Scharpf (1997, chapter 4).

[27] The assurance game (which is sometimes also called the 'stag hunt') has multiple Nash equilibria that could form its outcome, e.g. see Wikipedia 'Stag hunt', https://perma.cc/CN2H-BR2Y. One equilibrium reflecting desirable cooperation is 'payoff dominant', meaning that both players earn their highest payoff by cooperating. But this is risky for the players because, if Aardvark chooses to cooperate but Beaver does not, Aardvark is left with its lowest payoff. Therefore, a different equilibrium without cooperation is 'risk dominant', since it avoids this risk.

[28] Smith (1987).

[29] Milgrom (2004, pp.11–12), and McMillan (1994, pp.148–50).

[30] Mueller (1993, table 5, p.169).

31 McMillan (1994, p.146). For a trenchant, contrary view, see Nik-Khah (2008).

32 The proposal was made by Paul Milgrom and Robert Wilson (who a little under 30 years later became the joint winners of the Nobel Memorial Prize in Economic Sciences in 2020), working for Pacific Bell. There was a similar proposal from Preston McAfee, working for Airtouch Communications. Auction theorists were also employed by other potential bidders, and John McMillan worked for the FCC.

33 Milgrom (2021, p.1392).

34 Roth and Ockenfels (2002).

35 Milgrom (2000, p.249).

36 Milgrom (2004, p.22).

37 Milgrom (2021, p.1384).

38 Rodrik (2015, p.12).

39 Differences in objectives between the bid team and the firm's owners provide a possible rationale for the use of budget constraints – Bichler and Goeree (2017, section 4.4).

40 Armstrong and Huck (2010).

41 Milgrom (2011, p.312). Departures from equilibrium bidding are commonly observed in experimental analysis, such as Marszalec (2018).

42 Roth (2002), and McAfee and McMillan (1996).

43 See the account of 'economic engineers' by Alexandrova and Northcott (2009, p.333).

44 Roth and Wilson (2019, p.139).

45 More generally, the 1994 auction (and developments in US Treasury auctions) 'underscored some extremely serious limitations in auction theory', such as that 'relatively little was established concerning multi-item auctions' – Ausubel (2008, p.2).

46 Ausubel, Cramton, and Milgrom (2006).

47 Cramton (2013, section 4).

48 Milgrom and Segal (2020) call this format the 'deferred-acceptance clock auction'. Milgrom and Vogt (2021, section 5 in) explain how it addressed the incentive auction's challenges of computational complexity, bidder trust, winner privacy, budget conditions, avoiding incentives for collusion ('group strategy-proof'), price competitiveness, and minimising procurement cost.

49 Nobel Prize (2020b).

50 The UK avoided clear-cut failures, but potential exceptions to the success story are potential adverse effects on investment of very high revenue in the 2000 auction, and question marks about the efficiency of the spectrum allocation in the 2013 auction. The evidence in relation to both is mixed (as set out in Section 7.2 and Annex A).

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Note: means an open access publication.

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4. Regulation, public value, and policymaking

Summary

- Good regulation underpins well-functioning markets. But there are inevitably risks of regulatory failure, chiefly ineffectiveness and unintended consequences. A high-level framework that is appropriate for analysing many public policy issues is one that balances the twin risks of market failure and regulatory failure.
- Allocating radio spectrum to uses where it has the highest economic value is central to a rational-comprehensive approach to designing auctions. But some issues bring in broader values (such as equity and social cohesion) that are reflected in 'public value', especially questions of universal mobile coverage.
- The concept of public value encompasses not only the desirability of the outcome, but also the legitimacy and sustainability of the policymaking process.
- Market design can play an especially important role if experts are effective in engaging constructively in policy debate with officials to mitigate decision-making biases, such as overconfidence and limited attention.
- There are times when the incrementalism and bargaining of 'muddling through' are adopted in decision-making for auction design. However, sufficient expertise is needed to appreciate the risks and avoid embarrassing failures.
- For a regulator, a good reputation can strengthen its autonomy and effectiveness. Reputation can be enhanced by various mechanisms of accountability, such as voluntarily engaging in broader and deeper consultation than the minimum required.
- Within the regulator, the dynamic of the multidisciplinary team of different professional skill groups can devolve into negative coordination, such as turf wars where groups battle to protect their autonomy. Or, through constructive communication and mutual recognition, more positive coordination can be achieved to realise synergies from the interdependence of the work.

How to cite this book chapter:

Myers, Geoffrey (2023) *Spectrum Auctions: Designing markets to benefit the public, industry and the economy*, London: LSE Press, pp. 53–67. https://doi.org/10.31389/lsepress.spa.d. License: CC BY-NC-ND 4.0

The first section in this chapter outlines the role that regulation plays in market design, underpinning the operation of markets, and explains the importance of public value. The second section describes key features of decision-making by the regulator, including its independence, reputation management, mechanisms of accountability, and the coordination of its professional skill groups. The final section concludes with some wider lessons for public policy.

4.1 Regulation and public value

Although markets are often imperfect, so also are regulators. Therefore, the risk of regulatory failure is an important counterpart to the risk of market failure set out in the previous chapter. The idea of public value is important here as it provides a wider goal when designing markets than social value (which is maximised for economic efficiency).

The role of regulation

In many types of markets, regulation is limited, such as the general legal framework that governs private contracts or employment rights. Some sectors are subject to additional regulation, as with the effects of health and safety regulation on the construction industry. There are also many parts of the economy with a specific designated regulator, such as electricity, water, financial markets, or radio communications. Regulation can sometimes be considered a substitute for a market that is regarded as failing, such as price caps on retail energy prices. Or regulation can shape markets, often to promote competition, for instance in electricity generation and retail supply through regulated access to electricity transmission and distribution networks.

Spectrum auctions are one example of a more fundamental type of regulation that designs markets. These markets only come into existence and operate in the way they do because of conscious design to establish their rules and market infrastructure. Another example is the use in some countries of designed wholesale markets in electricity, sometimes with open access forward and spot markets (for future and immediate delivery, respectively), where generator companies sell electricity and retailer providers buy it. Regulation sets the rules of how these electricity markets work, and the market infrastructure may include a systems operator that operationally runs the market and is independent of both buyers and sellers.[1]

Not all designed markets have an independent regulator, and there are cases where the design is undertaken wholly by private companies. An example of such an auction-based market is for internet advertising. This often determines what advert you see when loading a web page via one or more auctions run within milliseconds. The choices made by large private companies, especially Google, determine how these auctions are designed.[2] Where such industry players carry out this role, they may be considered as performing a regulatory function of market design, as well as being market participants. But for the designed markets of spectrum auctions, it is a public sector regulator that sets the rules, operationally runs the market, and provides some market infrastructure, for example the auction software platform.

The job of regulation can be challenging in a world of imperfect choices and asymmetric information. Therefore, as well as assessing market failure, it is crucial to pay close attention to risks of regulatory failure. Just as markets can fail to deliver the optimal outcome, so too regulation can fall short, imposing direct and indirect costs, failing to achieve the desired objective, or leading to unintended consequences. Regulators often lack key information and have difficult trade-offs to judge in decision-making processes that can be slow, subject to human biases, and at risk of capture by particular interest groups. Regulatory agencies must navigate challenges of public organisations such as efficient operation, accountability, and coordination. Therefore, a high-level framework to analyse many issues is recognising the balance to be struck between *market* failure and *regulatory* failure.[3] Examples are policies to expand mobile coverage (Sections 5.3 and 10.2), band clearance and licensing (Chapter 6), and competition measures (Chapter 9 and Section 10.1).

Given the role that regulation plays in market design, there can be a false dichotomy between markets and regulation. But drawing a distinction between market failure and regulatory failure can still be helpful. To take a practical example, when a spectrum auction goes wrong, which applies? The answer depends on the reasons. There are auctions with sensible designs that ended rapidly or with undesirable outcomes due to lack of competition between bidders, a type of market failure. But there are also examples where problematic regulatory design led to long drawn-out auctions to the extent that the rules had to be changed during the auction itself to bring them to closure (such as Finland in 2013, Poland in 2014, and Portugal in 2021).[4] Later chapters provide further practical examples of regulatory failure, such as coverage obligations overpromising and under-delivering (Section 5.3), and adverse consequences of excessively high reserve prices (Section 7.3).

Public value

The success of a market is achieving desirable outcomes through socially appropriate means. There are different ways of thinking about what constitutes the desirability of outcomes or the means. For our purpose, we are especially interested in the intersection between ideas about market design and public value creation – 'Public value is created by public sector actors creating and co-shaping markets in line with public purpose'.[5] It emphasises the role of the public manager in policy development through a strategic and innovative approach to be 'explorers who, with others, seek to discover, define, and produce public value'.[6]

The starting points, perspectives, and preoccupations of public value and market design are very different, but both have much to offer the practitioner. Public value is explored in public management (or public administration), a scholarly field which has been described as the study and practice of design and operation of the arrangements for the provision of public services and executive government.[7] Another, more colourful description is 'a world of settled institutions designed to allow imperfect people to use flawed procedures to cope with insoluble problems'.[8] Public value creation involves producing what is valued by the public or adds value to the public sphere, highlighting longer term outcomes and processes.[9] Public value is envisaged as the public management equivalent of private sector shareholder value. This book analyses spectrum auctions through the prism of public managers within regulators who strategically link public value to market creation, with the scope to be ambitious in desired outcomes and innovative in their design choices.

Later sections and chapters investigate all three dimensions of the 'strategic triangle' for public value:[10]

- The authorising environment relates to the legitimacy and political sustainability of the regulator with government, politicians, and the public. This is examined in particular in Chapter 5. An example is how the position of the regulator and politicians can be affected by the revenue

raised in auctions, and by reputation management. The respective roles of the regulator and the government are also affected by the potential for split responsibilities or overlap in authority to promote downstream competition or to extend mobile coverage.
- The policy environment is to achieve a valuable outcome from spectrum auctions. For example, the outcomes of UK auctions are outlined in Sections 2.3 and 11.1 (and examined in greater depth in Annex A).
- The operating environment is about administrative feasibility. Sufficient operational capability is relevant both to design auctions (Chapters 7–10) and to implement them successfully (Section 11.2). The regulator's institutional strength can constitute part of the required market infrastructure, such as its expertise and a reputation for operational professionalism and trustworthiness (Section 7.6).

The regulator 'holds the ring' for spectrum auctions, but many other public and private players are involved. In this sense, it can be seen as co-creating public value along with other participants. Scholars may be involved as expert advisers, such as auction theorists and computer scientists. Stakeholders for key public policy concerns, like mobile coverage ambitions, include the government and civil society. Private companies are integral to the process as market participants. The way they bid in auctions represents their self-interest, often drawing on prior experience across multiple countries. They also use the spectrum to deliver mobile telephone and data services valued by consumers. For our purposes, therefore, a useful angle is four leadership roles for collaborative innovation, which can be taken on by the same or different actors: sponsors, champions, catalysts, and implementers.[11]

The first role is sponsors who have authority, legitimacy, and resources. For the auction itself, the regulator has legal authority, and its reputation affects its legitimacy (Section 7.6). But for some activities, it may be the government who also acts as a sponsor. A specific example is to obtain the spectrum to award, whether the government is the source of the spectrum (as for the 2018 auction) or it provides financial resources to fund the costs of clearance of existing users when there is a change of use (Section 6.1). More broadly, for issues of public sector revenue, including the monies generated by auctions, the finance ministry has authority (Section 5.1). Government departments can also be in the role of sponsor where broader public values are at stake, such as universal mobile coverage (Section 5.3).

A second role for collaborative innovation is champions with informal authority, who mobilise the capacities of their organisation to convene, organise, facilitate, and energise the collaboration process. The regulator interfaces with a range of stakeholders in government, the private sector, and academia. It could be to champion pioneering practical application of innovative auction formats, engaging with scholars to appreciate their characteristics (Section 3.3). Or it could be explaining their relevance and merits to policymakers and potential bidders (with risks of litigation). Internal experts within the regulator can play a valuable bridging function between scholars and policymakers (Section 5.1).

A third role is catalysts who create an appropriate disturbance to get participants to think 'out of the box'. Auction theorists can be catalysts, bringing valuable new ideas from the pages of academic journals to practical application, often through themselves being experts advising the companies bidding or the regulator designing the auction. They may develop enhancements or new auction formats in response to observed difficulties for bidders to express their preferences or to unforeseen bidding behaviour (Section 3.3).

The last role is implementers to get things done as visionaries, connecting big ideas with new norms. Spectrum auctions are implemented by the regulator. There is sometimes a trade-off between risk and reward, but there can be benefits from a bold approach of learning and well-judged innovation. Sometimes the government can be an implementer, such as when taking advantage of the benefits of direct procurement to extend mobile coverage. Mobile operators can also be implementers for social and public value, delivering benefits to citizens where they take on and comply with coverage obligations.

The next two subsections explore the two important differences for spectrum auctions in the idea of public value compared to social value (economic efficiency). Public value takes account of a much broader set of values and includes the nature of decision-making processes. Public value looms large when discussing universal mobile coverage and decision-making roles and processes in Chapter 5, while economic efficiency is central to much of the analysis in Part II of the book such as the application of auction theory in Chapters 7 and 8.

Broader values

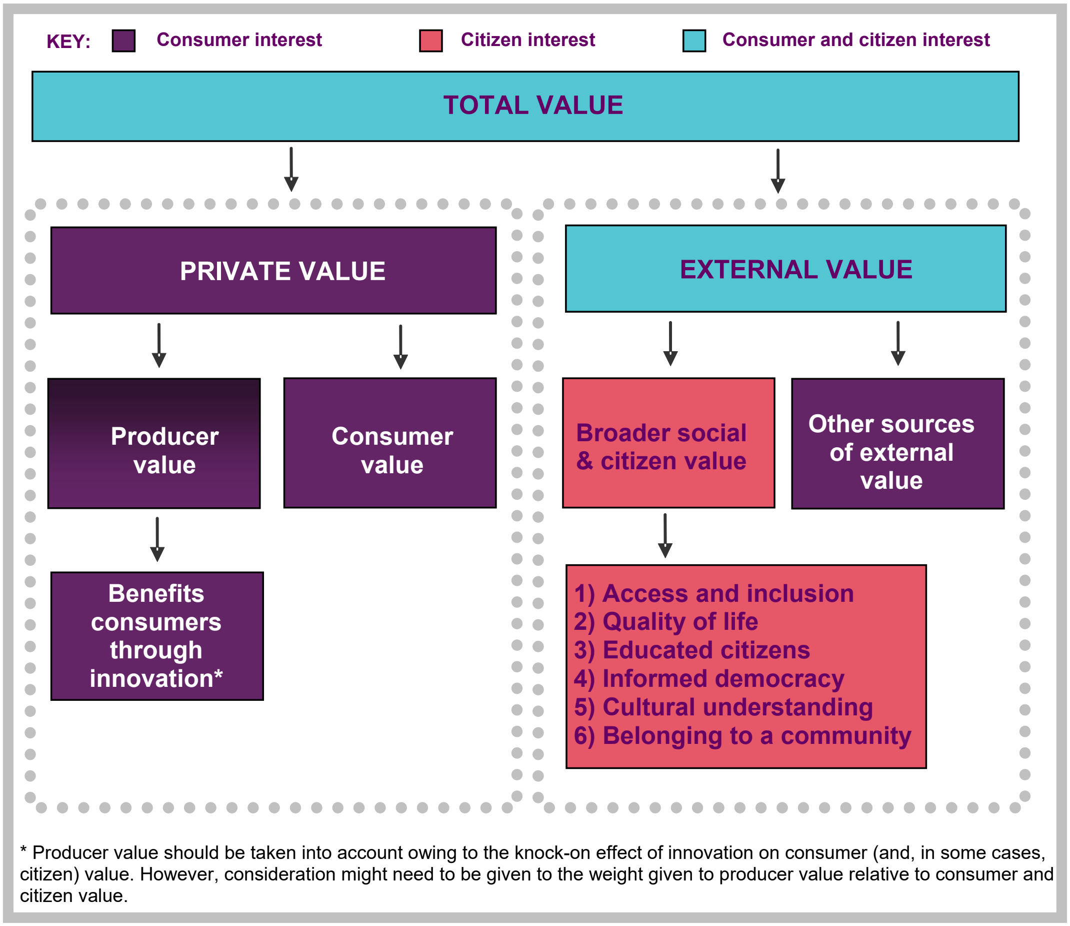
Economic efficiency is limited in the types of values it incorporates in social value, compared to the wider scope of public value. Broader values include, amongst many others, social cohesion, protection of minorities, accountability, integrity, equity, justice, and responsiveness.[12] An example of how some of these vital values for public policy can be embraced alongside the building blocks of economic efficiency is Ofcom's 'total value framework' in Figure 4.1. The private and external value elements in purple, labelled as 'Consumer interest', reflect economic efficiency. The framework also includes 'Citizen interest' through 'broader social and citizen value', capturing aspects of public value which are especially important, like informed democracy and belonging to a community, when developing policies in areas such as public service broadcasting or universal mobile coverage.[13]

The approach set out in Section 3.1 presented market failure as the rationale for intervention in markets. Some proponents of the public-value approach object to framing the analysis in this way as unduly limiting the scope for the public sector, presenting government intervention only as a 'residual category or an issue of technical efficiency in pricing structures'.[14] The more inclusive view of what constitutes the desired outcome for society embodied in the total value framework in Figure 4.1 can bring these two perspectives closer together, while maintaining the analytical rigour of market failure analysis. There are examples of this approach being implemented in spectrum policy and auctions.[15] For example, when assessing the benefits of improving mobile coverage through obligations in an auction in 2018, the UK regulator described broader social value as capturing:

> the benefit to citizens and society due to social goods that are enjoyed by most or all people in society, typically irrespective of income. Social goods that give rise to broader social value potentially include democratic freedoms, equality, tolerance of minorities, and other aspects of social capital and physical security.[16]

The broader social benefits of improved rural coverage were included in the qualitative analysis of the regulator's impact assessment. Examples were explicit analysis of social capital, sustainability of rural communities, and improved healthcare. Earlier research sought to understand broader social value generated by various services, including television and mobile broadband, through a range of quantitative and qualitative techniques asking people to distinguish between personal and societal benefits.[17] This research provided evidence of the significance placed by citizens on public value due to universal coverage of mobile broadband, regardless of whether people themselves lived in rural areas with patchy coverage or in well-served urban areas.[18]

Figure 4.1. Total value framework including broader social value



Source: Figure 4 in Ofcom (2007b), p.28. Copyright: Ofcom.

The value of this analytical approach, including a breadth of values when judging market failure, is to bring both the economic and public value perspectives within the same framework instead of separate conversations talking across but not with each other. The tension between values can present a challenge to make this inclusive approach work. But, when successful, the benefit of bridging different world views is a more connected and fruitful policy debate.

Rational-comprehensive decisions and muddling through

A second way in which public value is broader than economic efficiency is that it encompasses behaviour and the validity of decision-making processes. The strategic triangle for public value includes political sustainability in the authorising environment, as well as a valuable policy outcome and operational feasibility. Key market design principles matter for spectrum auction practitioners, but effective public managers need also to be influential in policymaking, not just narrow technocratic experts. Some of the implications of this difference can be illustrated by drawing the distinction between two types of decision-making: the rational-comprehensive method of market design experts, and the pragmatic incrementalism or 'muddling through' (a label used purely descriptively without pejorative intent) often practised by public managers. In simple terms, the rational-comprehensive approach is a thorough analysis (from the root) to assess the most appropriate means to achieve clearly specified objectives, often relying heavily on underlying theory. In contrast, muddling through involves incrementalism of successive limited comparisons (branch, not root), where means and ends are not distinct, and acceptable outcomes are sought through consensus building and bargaining, taking a pragmatic approach.[19]

Although incrementalism is a key part of muddling through, the complete model contains additional elements, illustrated in the more granular comparison with the rational-comprehensive approach in Figure 4.2. Identifying well-defined objectives is the starting point for rational-comprehensive analysis, but objectives are not distinct from one another in the muddling-through model. Good policy is assessed under the rational-comprehensive approach as the most appropriate means to generate identified ends. In contrast, means and ends are not considered to be distinct when muddling through, and good policy just means achieving consensus – for example, alternative policies embody different trade-offs between values, so that it is only reaching agreement on the policy that crystallises the relevant weight on different objectives. The extent of analysis is another source of difference, whether comprehensive or instead drastically limited for muddling through. The models also differ in the importance of theory, which rational-comprehensive analysis relies on heavily, but its use is greatly reduced in the muddling-through approach. The full-blown versions of both models are quite extreme, and in reality are more usually practised in modulated form. For instance, the rational-comprehensive style of analysis in practice may just assess the main options instead of a fully comprehensive set. Or decision-making with key elements of muddling through may still judge outcomes through an indication of desired ends, even if they are not precisely formulated, and not solely on the basis of achieving consensus. Also, practical decision-making can share features of both models, and the primary approach can vary through the life cycle. Spectrum auctions typically involve a lengthy

Figure 4.2. Comparison of decision-making models: rational-comprehensive and muddling through

	Rational-comprehensive (root)	Muddling through (branch)
Objectives	Objectives or values are well-defined.	Objectives are not distinct from one another.
Means and ends	Ends are identified, then means to achieve them are assessed.	Means and ends are not distinct.
Good policy	Policy is the appropriate means to achieve the desired ends.	Relevant people agree with the policy (consensus).
Analysis	Analysis is comprehensive.	Analysis is incremental from the status quo and drastically limited, ignoring important outcomes, options, and values.
Theory	Theory is often heavily relied on.	The reliance on theory is greatly reduced or eliminated.

Source: Author from Lindblom (1959).

process, allowing plenty of time for evolution – for example, policy development for each of the UK's high-stakes auctions extended over significantly more than a year.

The market design analysis for an auction is in the rational-comprehensive mould. It starts from a clear statement of auction objectives. It then proceeds through a detailed assessment of design issues that draws heavily from auction theory. Alternatives are considered before reaching a decision on the most appropriate auction design in the circumstances. Much regulatory decision-making follows this analytical procedure. The *raison d'être* and reputation of independent economic regulators is to make reasoned, evidence-based decisions.

Muddling through can play several roles in the analysis. Section 5.1 shows how an incrementalist approach is sometimes used for auction design decisions, starting not with a blank sheet of paper to decide what is best suited to the circumstances, but tweaking a pre-established design. One example is when conditions were sufficiently similar in the UK between one auction in 2018 and the next in 2021. However, there are also other examples of embarrassing consequences in Finland and Portugal when the regulator did not utilise sufficient expertise to judge the consequences of incremental modifications. A second use of incrementalism was described in the wider process of auction design over time in Section 3.2, involving both evolutionary and more radical changes. There are elements of incrementalism in the path dependence and the adjustment to feedback from prior auction experiences.

A third role is that public policy decision-making processes often involve consensus and bargaining. Experts can increase their influence by recognising that the rational-comprehensive approach from which they draw their technical expertise is not the whole story. To be effective, the market design expert must also engage in muddling-through processes of bounded rationality where trustworthiness, reputation, and communications skills come to the fore to build consensus, and biases in human decision-making can be on display. Much analysis of behavioural insights is applied to individuals as consumers, whereas the focus here is on how behavioural biases affect decisions by public organisations, so-called behavioural public administration (or how biases affect private companies, such as providing a possible reason for overbidding in the UK's 2000 auction).[20] Within the regulator, senior managers and decision-makers need to be armed with the understanding to make informed judgements, when obvious or hidden complexities can create biases of under-confidence in CCAs or overconfidence in SMRAs, respectively (Section 5.1). Salience of coverage obligation headlines and limited attention on complex engineering details that affect the realised mobile experience for consumers present risks of regulatory failures (Section 5.3). A different type of adaptation is to the demands of the legal arena as an expert witness to assist the court – a role that I have undertaken – shedding light not heat on the matters in dispute (Section 5.4).

4.2 Regulatory decision-making

This section explains conceptual underpinnings for regulatory decision-making (drawing on the UK experience), including independence, accountability, and reputation management, as well as the coordination challenges professional skill groups face within the regulator.

Regulatory independence and reputation management

The regulator that designs and runs the auction is either part of a political ministry or an independent agency. Regulatory independence, whether formal and based on statute or informal 'rules of the game', can be a matter of degree.[21] For instance, there is evidence of UK regulators becoming more responsive to political concerns over time.[22] There can be a number of reasons to structure a regime that has decisions being made by an independent agency, such as specialist expertise for efficient implementation, policy independence from political influence, credible commitment to consistent decision-making over a longer time horizon than many political decisions, and trading off various types of transaction cost (such as political decision-making, commitment, agency, and uncertainty).[23] Another possible reason is to shift blame from politicians to agencies.[24] Blame shifting is not always successful in the context of spectrum auctions, when the revenue raised is significant for public coffers and tends to dominate the media coverage. Section 5.1 tells the story of criticism that revenue generated by the UK's 2013 auction fell short of expectations, which was a case of a blame 'boomerang' back to politicians, even though the auction was designed and implemented by the independent regulator.

A stylised characterisation of the regulator's decision-making structure is that much of the work is conducted by a project team composed of multiple professional skill groups. These include internal experts in auction design, competition assessment (antitrust analysis), spectrum engineering, information security etc. In addition, external expert advisers, such as scholars or consultants, may be involved. There are also decision-makers and senior management who are concerned about the positioning of the organisation in the public sphere and managing its reputation as well as having in mind the focused objectives of the auction. A good reputation can strengthen regulatory autonomy and assist in weathering storms from hostile stakeholders, which can include politicians, private sector companies, or the media. The regulator sometimes needs to navigate choppy waters, such as avoiding blame for revenue being below expectations or perceptions of money being left on the table (Section 5.1). Reputations of public organisations have multiple dimensions, such as performative, moral, procedural, and technical.[25] These are all relevant to spectrum auctions to the extent that the regulator's reputation can be classified as part of the infrastructure of successful markets (Section 7.6). The performative dimension of reputation relates to the regulator's competence and effectiveness, in both designing and implementing auctions. The moral aspect includes honesty, such as running the auction with integrity and impartiality without fear or favour. Procedural considerations mean following the auction rules and accepted norms so the process is seen to be fair. The technical dimension is about the regulator's skills and capability, such as provided by internal and external experts.

Mechanisms of accountability as required by statute and undertaken voluntarily can strengthen the regulator's reputation, especially because it lacks direct democratic legitimacy.[26] This can explain a common practice of regulators to engage in broader and deeper consultation than the minimum required by law.[27] Another type of accountability is that regulatory decisions can be appealed to the courts – it is not unusual for operators to initiate litigation, and threats to do so are even more common. Complaints can be about design rules, such as competition measures which are generally controversial because spectrum caps and reservation have differential effects on operators. As an example, the caps in the UK's 2018 auction placed limits on the bids that could be made by one operator (EE), but imposed little restriction on other firms. Section 5.4 examines the litigation of spectrum caps that occurred in advance of this auction, focusing on the role of the expert.

There are stark contrasts between the regulator's degrees of control over different parts of the auction process. During the policymaking phase the regulator makes decisions within its remit (although for issues affected by litigation, judgment shifts to the courts). When implementing the auction, the regulator specifies the procedures to be followed, such as the application process for companies to participate in the auction. It provides the bidding software (usually procured from specialised suppliers), and it sets price increments and the schedule of rounds per day (Section 11.2). But it is operators that determine the outcome through their bids. Being inside the regulator's auction room can, therefore, be a rewarding or fraught experience, waiting to see if the carefully chosen design will pay dividends, and powerless if it does not.

Coordination between skill groups within the regulator

The regulators' decision-makers are assisted by the multidisciplinary project team. To work well, the team needs to coordinate contributions from the constituent skill groups, each of which tends to come at the issues from a different perspective, reflecting its professional norms and mode of analysis. For example, assessment of the downstream competition effects of spectrum auctions can be especially dependent on collaboration between a range of professional skill groups. Standard antitrust reflects a confluence between legal and economic analysis, and the outcome of competition analysis for spectrum auctions further relies on deep understanding of regulatory policy and spectrum engineering. This can generate powerful benefits of 'positive coordination' to realise synergies from team-working. But there are also risks of tensions. When the dynamic does not work well, it is manifest in miscommunication, frictions, disagreements, and failure to realise synergies. The team can devolve into 'negative coordination' where, to avoid conflict, the outcome is constrained by groups' self-interest (such as threat or exercise of vetoes).[28] A contributory feature can be the selective perception of specialised skill groups, failing to see how their analysis interacts with others' work. Groups can also have blind spots that lead people to revert to previously established approaches instead of seeking collaborative innovation.[29] They can also seek to protect their autonomy or 'turf'.[30]

We can analyse the relationship between skill groups by combining ideas about coordination and motivation, and adapting to this context several concepts also deployed in Part II to investigate auction design issues. Effective collaboration can achieve synergies where the output of the whole team delivers more than the sum of the individual parts (analysed for spectrum valuations in Section 8.2). We can also think of different skill groups needing to 'trade' with each other to achieve the desired outcome, with the mutual gains providing incentives if barriers to trade are low enough (in an analogy with the 'Coase theorem' used in Section 6.2 to analyse spectrum licensing). The applicable decision-making process has elements of the bargaining aspect of muddling through, within an overarching more rational-comprehensive analysis of the substance of the competition assessment itself.

The interdependence of the work of professional skill groups means they can be characterised as being able to impose externalities or spillover effects on each other. The externalities can be either positive (consistent with synergies) or negative, such as failing to identify and clearly communicate prerequisite analysis that another skill group needs. For example, the economic analysis needs to be framed in terms of the relevant legal duties and tests, or the construction of an engineering model changes with the policy question it is intended to address. The trading or exchange between skill groups to internalise these externalities is non-monetary and depends on overcoming barriers or 'transactions costs', such as vetoes by skill groups that are a feature of negative coordination. An example of reducing barriers is the regulator embedding team negotiations within a hierarchical structure, with senior management expecting or mandating agreement (consensus) between the skill groups.[31] Other barriers and the nature of what skill groups exchange depend on their motivations.

There can be a wide range of sources of motivation, as illustrated in Figure 4.3. A stylised distinction in public service motivation is between altruistic 'knights' seeking to help others, and self-interested 'knaves' whose actions can still result in desirable outcomes in the right context.[32] Motivation for knights can be intrinsic, internal to the individual such as obtaining a 'warm glow' from helping others.

Figure 4.3. Sources of motivation: knights and knaves, intrinsic and extrinsic

	Altruistic 'knights'	Self-interested 'knaves'
Intrinsic motivation	Warm glow from helping others	Autonomy and enjoyment of task
Extrinsic motivation	Identity, recognition, and fairness	Financial rewards

Source: Author.

It can also be extrinsic like identifying with the social norms of a professional group or achieving wider recognition.[33] For knaves, the extrinsic motivation through financial reward is less relevant to our current context. But self-interest of autonomy and task enjoyment that social psychologists would classify as intrinsic motivation is very much in play.[34] Professionals such as economists, engineers, or lawyers enjoy interesting analysis in their respective specialisms. It can be a key reason for them to work for a public organisation instead of plying their trade in usually better-paid jobs in the private sector. Engaging these sources of intrinsic and extrinsic motivation can assist incentives for cross-group working, so that each skill group is less likely to perceive the situation as akin to the incentives not to cooperate in the prisoner's dilemma game (Section 3.2).

Collaboration to realise synergies is facilitated by lowering barriers through clear communication of how the work of each skill group contributes to the team's interdependent output. This fosters shared beliefs in working towards a common goal, such as a warm glow from the team delivering an evidence-based competition assessment, ultimately to benefit the public. Other contributory actions include appreciation of each other's perspective and motivation, allowing each skill group enjoyment from its work and bolstering professional identity. Collaboration also benefits from people achieving recognition within the team, more widely in the organisation, and from external stakeholders such as through publication of the analysis. Such low barriers and constructive exchange between skill groups can help the multidisciplinary team dynamic to work well, and achieve positive coordination, maximising joint effectiveness and efficiency.

Therefore, at its worst the multidisciplinary team, like different public organisations that need to coordinate, can suffer from turf wars, with each skill group having an unclear remit, insufficient autonomy, and a weak match between its mission and jurisdiction.[35] At its best, the team can operate as a self-organising network of high-trust relationships.[36]

4.3 Wider lessons for public policy

This chapter shows how the intersection between public value creation and markets can be navigated to bridge narrower, rigorous economic efficiency and wider notions of public value. Both can be embraced – see, for example, the total value framework that includes broader social value (Figure 4.1). Such an *inclusive* analytical approach faces challenges. But it is more constructive than devolving into separate conversations between policymakers and economists that can talk across but not with each other. Taking the example of spectrum auctions, economic efficiency is central to a rational-comprehensive approach to decisions about designing the auction. However, universal mobile coverage is a policy issue that includes an assessment of economic benefits and costs but also brings in broader considerations reflected in public value, such as social capital and sustainability of rural communities.

Markets can fail to deliver public value, but so also can public policy or regulation. Many issues can be fruitfully analysed as a balance between the twin risks of *market* failure and *regulatory* failure. An example is the UK's consistent approach to promote downstream competition through spectrum auctions. Competition measures, such as spectrum caps and reservation, guarded against the market failure risk of weak retail competition. But the choice of specific competition measures also paid attention to the regulatory failure risk of excessive restrictions that would unduly limit the auction outcomes. Experience with spectrum reservation worldwide is mixed, and less successful examples are reported in Section 9.2. However, the UK's track record has been much more positive.

Notes

[1] Cramton (2017).

[2] For a detailed competition assessment of internet advertising markets in the UK, see Competition and Markets Authority (2020).

[3] Joskow (2010).

[4] Changes during Finland's 2013 auction were to limit price reductions when bids were withdrawn and avoid a repetitive pattern of prices going up and down – see DotEcon (2019, p.49). The change during Poland's 2014 auction was to curtail the auction with a final round of sealed bids – see Kuś (2020). During Portugal's 2021 auction changes were made both to the schedule of rounds and the minimum bid increment, as set out in Section 11.2.

[5] Mazzucato and Ryan-Collins (2022, abstract).

[6] Moore (1995, p.20).

[7] Hood (2009, p.8).

[8] Wilson (1989, p.375).

[9] Bennington (2011).

[10] Moore (1995).

[11] Crosby, 't Hart, and Torfing (2017).

[12] Jørgensen and Bozeman (2007). Economists recognise the relevance of many of these values, such as equity and questions of income distribution. The logic often used is that separate policy instruments (such as taxation) can address distributional concerns. But, if (as in practice) they fail to do so fully, distributional concerns can remain relevant.

[13] The labels of consumers and citizens reflect Ofcom's two-pronged principal statutory duty to further the interests of both 'citizens in relation to communications matters' and 'consumers in relevant markets, where appropriate by promoting competition' – Communications Act (2003, section 3(1)).

[14] Bozeman (2002, p.150).

[15] Barwise et al. (2015).

[16] Ofcom (2018b, paragraph A11.57).

[17] Market research methods included conjoint, chip allocation, Gabor-Granger, attitudinal, and deliberative research — see Ofcom (2007b, section 7 and annex 2), and Ofcom (2006b).

[18] Ofcom (2007b, paragraph A2.283).

[19] Lindblom (1959). For a critique, see Pal (2011).

[20] Battaglio et al. (2019).

[21] Stern (1997).

[22] Koop and Lodge (2020).

[23] Levy and Spiller (1996), and Horn (1995).

[24] Hood (2002).

[25] Carpenter and Krause (2012).

[26] For an overview of the balance between democratic accountability and independence in regulators and other 'non-majoritarian institutions', see Bovens and Schillemans (2020).

[27] Busuioc and Lodge (2016).

[28] Scharpf (1994).

[29] Wegrich (2019).

[30] Wilson (1989).

[31] Scharpf (1994).

[32] Le Grand (2003).

[33] Akerlof and Kranton (2005).

[34] Cerasoli, Nicklin, and Ford (2014).

[35] Wilson (1989).

[36] Scharpf (1994).

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5. Applying expertise in decision-making processes

Summary

- Effective experts assist, rather than supplant, policymakers by having an inclusive perspective that grapples with practical challenges and acknowledges wider values. In turn, policymakers obtain dividends, such as avoiding embarrassing failures, from taking notice of well-chosen expert advice.
- Auction design can raise challenges for lay policymakers, such as under-confidence in using more complex solutions like the CCA design. Or there can be opposing risks of overconfidence in the relatively simple mechanics of sealed-bid auctions and the SMRA format, which can obscure their strategic complexities.
- Regulators can be blamed for spectrum auctions that are perceived as failures. Or blame can boomerang to politicians, such as when revenue was below expectations in the UK's 2013 auction.
- When allocating decision-making authority between political ministries and regulators, the balance differs depending on the policy issue at stake, such as coverage or competition. There are advantages for socially important mobile coverage extension judgements to be made by ministries, headed by politicians with democratic legitimacy. In contrast, independent regulators with specialist expertise are better placed to make more technocratic decisions about competition measures.
- There is a temptation to incorporate coverage obligations into auctions as a way of extending rural coverage. But this should be balanced with recognition of regulatory failure risks of overpromising and under-delivering. Such risks stem from behavioural biases of excessive attention on simplified headlines and limited attention on 'the devil in the details'.
- Other ways to improve coverage exist and can be preferable to obligations in auctions. For example, direct procurement in the 2020 coverage agreement between the UK government and mobile operators offered more in public value and economic efficiency.

(*Contd.*)

How to cite this book chapter:

Myers, Geoffrey (2023) *Spectrum Auctions: Designing markets to benefit the public, industry and the economy*, London: LSE Press, pp. 69–92. https://doi.org/10.31389/lsepress.spa.e. License: CC BY-NC-ND 4.0

(Continued)

- Litigation can result from contentious regulatory decisions. Expert witnesses can be most effective by shedding light (not heat) on the issues to assist the court, instead of focusing just on defensive advocacy.

This chapter explores challenges about applying expertise in practical decision-making processes, using a range of examples drawn from experiences in spectrum auctions. The first section covers the auction design, and subsequent sections address promoting downstream competition, extending mobile coverage, and the role of experts in litigation (taking the example of contentious competition measures). For narrative purposes, the stories are told in this order. Key points and cross-cutting themes are summarised in Figure 5.1. The columns show the three topics of designing the auction, promoting downstream competition, and extending mobile coverage. The rows show four cross-cutting issues: the role of experts, behavioural biases, blame and reputation management, and coordination between public organisations.

The role of experts in practical processes is present in all three topics in the first row of Figure 5.1. For auction design it illustrates differing demands of communicating rational-comprehensive analysis and sufficient use of expertise in incrementalist decision-making. In litigation about promoting downstream competition, the expert needs to translate mastery of economic analysis to the different arena of the courts where issues are framed to answer questions of law. For extending mobile coverage it is experts in spectrum engineering who can demystify complex technical dimensions of mobile coverage.

Experts can also play a role in mitigating risks from behavioural biases in human decision-making in the second row of Figure 5.1 (while recognising that experts have their own biases, such as from the world view of their professional norms).[1] There are potential biases of under- or over-confidence in the choice of auction format. For coverage requirements, the salience of headlines and limited attention on implementation details give rise to regulatory failure risks of overpromising and under-delivering.

Blame and reputation management in the third row are influenced by the issues that attract public or media attention. The revenue generated tends to dominate media reporting of auctions even though it is generally less important than economic efficiency and public value. Politicians were the unjustified blame magnet for revenue from the UK's 2013 auction falling £1 billion below the pre-auction forecast. It was unjustified because the forecast was made by an independent agency, it was the regulator not politicians that controlled the auction design and implementation decisions, and maximising revenue was not an auction objective. For mobile coverage extension, policy announcements can attract public credit. But potential blame for subsequent under-delivery is obscured by a disconnect from messy implementation details.

The last row in Figure 5.1 relates to coordination between public organisations. In general, organisations can suffer from selective perception, Achilles heels, and blind spots. Multi-organisational sub-optimisation can arise from turf wars.[2] Where there is a degree of policy interdependence, three specific types of problem can arise: information mismatch, overlap (or 'underlap') in authority, and policy inconsistency.[3] Ministers are responsible for deciding competition measures in some countries, not regulators, which can pose problems of information mismatch. Mobile coverage is a policy area

Figure 5.1. Cross-cutting decision-making issues in Chapter 5

Issue	Designing the auction (Section 5.1)	Promoting downstream competition (Sections 5.2 and 5.4)	Extending mobile coverage (Section 5.3)
Experts	Auction design experts communicating their rational-comprehensive approach to decision-makers. Incrementalism leading to flawed auctions without sufficient use of design expertise.	Antitrust expert witnesses adapting to the demands of litigation to shed light not heat for the court.	Engineering expertise clarifying complications of how to set and monitor coverage requirements.
Behavioural biases	Lay policymakers having under-confidence in the CCA format and overconfidence in the SMRA format.		Salience of headline requirements and lack of attention on complex implementation details leading to regulatory failure of overpromising and under-delivering.
Blame and reputation management	Blame boomerang to politicians from media attention on the 2013 auction revenue falling below expectations.		Credit from attention focusing on policy announcements, with complexities obscuring blame for under-delivery in implementation.
Coordination between public organisations		Coordination being required between organisations (as in Australia), or integrated decisions by a single regulator (as in the UK). Australia changing from the minister making the decisions to the spectrum regulator for auctions after 2021.	Overlap in responsibilities in the UK between the government and the regulator risking policy inconsistency. Policy tools differing between direct procurement by the government and coverage obligations by the regulator.

Source: Author.

where the government and the regulator can have an overlap in authority (as in the UK) using different policy tools – direct procurement by the government, compared to coverage obligations imposed in spectrum auctions by the regulator – with an associated risk of policy inconsistency. Later sections of this chapter develop an argument for a contrast in allocating decision-making roles, striking a different balance between the values in play and specialist expertise. For socially important mobile coverage extension, there are virtues in direct procurement by ministries, headed by politicians with democratic legitimacy. In contrast, independent regulators are better placed to make more technocratic decisions about competition measures. Consistent with this view, a change occurred in Australia to shift decision-making for competition measures from the minister to the spectrum regulator. The change reduced the required coordination between organisations. But two agencies are still involved, unlike integrated decisions by a single agency as in the UK.

After summarising these four cross-cutting issues, the rest of the chapter provides practical examples, starting with the topic of auction design decisions. The final section then draws out wider lessons for public policy.

5.1 Governance and expertise in auction design decisions

The Covid-19 pandemic highlighted questions about the role of experts in public policy decisions.[4] This section assesses such issues for market design experts, whether external advisers such as leading scholars, or internal employees of the regulator. High-level lessons are for experts to see beyond their technical skills, and for policymakers to have access to sufficient expertise. In the first subsection, experts require skills in communication and influencing to mitigate risks of biases in decision-making from auction formats which have complexity front and centre (CCA) or less obvious (SMRA). A second set of difficulties is to combat outside challenges like low revenue falling below expectations, highlighting that the regulatory core skill set includes reputation management. The last subsection shows examples of the role for consensus-building, bargaining, and incrementalism. It illustrates risks for decision-makers without enough expertise to appreciate implications of the auction design choices.

Under-confidence in the CCA and overconfidence in the SMRA

Taking the CCA format first, the intention and basic ideas can be communicated and readily understood: package bidding to allow bidders to express synergies in their values for the spectrum in the auction, and a second-price rule seeking to incentivise straightforward bidding. But senior decision-makers probing beneath the surface or delving into greater detail, as they typically would in any major regulatory project, run into an unusual problem in my long experience in regulation across a wide range of disparate issues. Despite best efforts, it is genuinely difficult to explain some of the important intricacies of the CCA in a way that allows intelligent and experienced people, but non-experts in auction design, to feel confident about the depth of their understanding to make judgement calls. Examples include the following difficulties (see Section 8.1 and Annex B for detailed explanations of the CCA format):

- Thinking in terms of package bids and second prices is much less intuitive to most people than individual bids and pay-as-bid prices.
- In a package auction context, the meaning of highest losing bids to set second prices can be complicated (as an example, there are eight distinct highest losing bid components to Vodafone's price in the UK's 2013 auction).
- The winning spectrum allocation is determined using a 'black box' algorithm, which finds the best fit of the highest-value package bids to the available spectrum.

- The CCA has complicated mechanics. An example is the 'activity rules', which place restrictions on the bids that an operator is permitted to make depending on its earlier bids, such as not increasing the amount of spectrum bid for as prices rise. The intention is to encourage straightforward bidding. But understanding the detail requires a degree of expertise and is difficult for non-specialists.

The complications of the CCA can induce suspicion of 'smoke and mirrors'. One type of reaction can be along the lines of 'that's very clever, but is it too clever?'. This refers to a general and reasonable concern that something could go wrong due to the complexity, such as mistakes in running the auction or bidders exploiting loopholes that are hard to foresee. Complexity similarly presents governance challenges for decision-making processes of bidders. One consequence is that an unusually high degree of trust is required by the decision-makers in the reliability and judgement of their experts, whether internal or external. Another is that the lesser degree of confidence about the depth of their understanding can lead regulatory decision-makers to be more susceptible to stakeholder pressure. Heavy stakeholder criticism can make decision-makers hesitant that they – or their experts – may be missing something.

Criticisms by operators can be a mix of meritorious points and rent-seeking intended to shift the design in their favour. Because every spectrum auction design has weaknesses, there are valid arguments that can be made against the CCA format. But there is also empirical evidence of higher prices in CCAs than in SMRAs.[5] Bidders' self-interest, sometimes combined with genuine concerns, can lead to vehement complaints about price-driving risks in the CCA. Price driving, a bid strategy designed to increase the auction prices paid by rivals, is a possibility, as explained in Sections 8.3 and 8.4. However, it is also the case that the main alternative format, the SMRA, is prone to demand reduction or market division (tacit collusion), which are types of strategic bidding designed to reduce auction prices. So price differences between CCAs and SMRAs could in part be explained by artificially low prices in the SMRA as well as, or instead of, unduly high prices in the CCA.

The CCA is certainly not an auction format to be adopted lightly and is especially risky for a regulator without sufficient access to expertise, including reputational exposure from its complexity and contentiousness. But the consequence of the pressures is that under-confidence in the CCA can be a barrier to its adoption, even in suitable circumstances. It is not an insuperable obstacle, as CCAs have been run in a range of countries including Austria, Australia, Canada, Denmark, Ireland, Mexico, the Netherlands, the Slovak Republic, Slovenia, Switzerland, Trinidad and Tobago, and the UK. But it remains a practical impediment to be overcome nonetheless.

The SMRA design presents an opposite governance challenge of overconfidence, which is a commonly observed feature of human decision-making.[6] Despite the simpler auction mechanics, as explained in Section 8.2, bid strategies in the SMRA can suffer from complexities for bidders seeking to manage risks of aggregation if there are synergies. Substitution risk can also be a concern as it is possible for bidders to get stuck as the standing high bidder for lots they do not want. For the regulator, strategic bidding such as demand reduction and market division can be a threat to the auction objectives being successfully achieved. However, with the much more intuitive mechanics of the SMRA, there is a risk that decision-makers can be overconfident about the depth of their understanding and as a result underweight the weaknesses.

Part of the expert's role is to counterbalance these contrasting risks of bias in the decision-making process through effective engagement, building rapport, and demonstrating trustworthiness and reliability. Far from hiding complexities or risks, they should be addressed directly through explanation of their roles and benefits. Experts should also be attentive and responsive to policymakers' concerns and practicalities, even if they stray outside core analytical issues.[7] Effective expertise is about carrying justified influence in policy debates, not just being able to apply the complex auction theory. A cartoon by Randy Glasbergen provides a cautionary tale, the opposite of what is required, of a man telling his wife over dinner: 'I gave a presentation today but I only pretended to know what I was talking about. Fortunately, my audience was only pretending to listen.'[8]

Money left on the table and blame magnets

For politicians engaged in the 'blame game', as well as presentational and policy strategies, blame can be shifted to public agencies through delegation of authority.[9] Regulators have decision-making powers and are often blamed for unsuccessful auctions, such as criticism of Portugal's 2021 auction by the Prime Minister.[10] However, blame can also boomerang, rebounding back to politicians.

An issue with CCA or sealed-bid auctions using the second-price rule is the potential for reputational embarrassment from the perception of money being left on the table. This is due to the gap between the amount of the winning bids and the prices. For example, the first spectrum auction in New Zealand used a sealed-bid, second-price format with no reserve prices. Some extremely low prices caused adverse publicity – as noted in Section 3.3, some winners paid less than 0.1 per cent of their own bids due to very large gaps to the highest losing bids. Even short of these extreme examples, Sky Network TV paid a price of NZ$ 0.4 million each for three lots, representing only 17–18 per cent of its winning bids of NZ$ 2.2–2.4 million.[11] However, the gap between prices and bids with a second-price rule, including in the CCA, is a feature not a bug. The rationale is that, in a simple case, it provides incentives for companies to bid straightforwardly at their full value.[12] A lower bid only reduces firms' chances of winning and does not affect the price they pay if they win, because the price depends on the highest losing bids made by other bidders. Because, by definition, losing bids are lower than the winning bids, a gap can arise in well-designed auctions, as shown in Figure 5.2 for the UK's 2013 auction. The operators that won spectrum in the auction are in the rows. The first column shows the bid amounts of the winning bids in millions of pounds. The second column shows the prices paid for the spectrum, set according to a second-price rule. The third column shows the gap – the price expressed as a percentage of the operator's winning bid.

Figure 5.2. The gap between winning bid amounts and prices in the UK's 2013 auction

Operator	Winning bid amount (£ million)	Price paid (£ million)	Price as a percentage (%) of winning bid
BT	340	186	55
EE	1,050	589	56
H3G	566	225	40
Telefónica	1,219	550	45
Vodafone	2,075	791	38
Total	5,249	2,341	45

Source: Author from Ofcom auction documents.
Note: Winning bids and prices are rounded to the nearest £ million

All of the information in Figure 5.2 was published by Ofcom at the end of the auction, showing a large gap as prices were only 45 per cent of winning bids overall. EE had the smallest gap but still paid only 56 per cent of its winning bid. Of course, the winning bids were as large only because the bidders knew that a second-price rule was being used. If a first-price rule had been used in the sealed-bid stage of the CCA, there would have been very strong incentives for 'bid shading', bidding below full value to obtain lower prices (balanced by bidders against reducing their chances of winning). Therefore, the use of a second-price rule does not mean that the prices paid are necessarily lower, despite the perception of leaving money on the table. For example, in an SMRA, the winning bidders do not have to bid up to their full value and need only to outbid the losers. Indeed, as noted previously, prices in CCA spectrum auctions tend to be higher.

The absence of a statutory objective for revenue-raising seemed to insulate Ofcom's reputation to a large extent from criticism or adverse publicity. For example, the report by the National Audit Office, an organisation whose role includes criticising public agencies for not obtaining value for money or a fair return on public assets, did not do so in this case. It recognised Ofcom's objectives derived from its statutory duties, and indeed suggested that promoting benefits from efficient use of spectrum were more important than maximising revenue.[13] In the immediate news reporting at the time, there may have been a benefit from the complexity of the CCA. While all the information in Figure 5.2 was in the public domain, it was not presented in such a stark way, and it required people who knew their way around the data to put it together. Most countries running CCAs just publish the winning outcome of the spectrum allocation and the prices, not the winning bid amounts, meaning that the gap is never made public.

Another explanation for the relative lack of public criticism of Ofcom is that politicians provided an alternative blame magnet. The news reporting focused on the gap between the revenue of £2.3 billion and the pre-auction revenue forecast by an independent agency, the Office of Budget Responsibility, of £3.5 billion.[14] Some analysts provided well-informed, more sophisticated commentary.[15] But the general sentiment was summed up in a cartoon by Kip Williams of an auctioneer at a lectern with a gavel saying: 'What am I bid for this ritual humiliation of the Chancellor?'.[16] As an objective assessment of the auction, this was hardly fair, as the Chancellor of the Exchequer, head of the UK finance ministry, neither designed the auction nor produced the revenue forecast, and economic efficiency matters more than revenue. However, the media and public reaction is not always objective, nor is blame necessarily a fair process.

Consensus, bargaining, and incrementalism: muddling through

Another dimension is the type of decision-making process that is in play. Section 4.1 described the models of rational-comprehensive decision-making and muddling through. The in-depth analysis of auction design in Part II reflects a rational-comprehensive approach. Here, aspects of muddling through are explored: consensus, bargaining, and incrementalism.

Consensus is internal to the regulator, initially at team level and then through governance. The multidisciplinary team investigates, develops its analysis, works up options, and develops a preferred view (see Section 4.2 for coordination challenges in team dynamics). Internal experts are deeply involved throughout and external experts consulted at key points. Different professional skill groups make complementary contributions, such as economists, accountants, policy advisers, engineers, and lawyers. Disagreements are worked through, usually strengthening the analysis. Senior decision-makers are consulted individually and collectively, first to provide steers and stress-test the team's work, and then for decisions. It is not that everyone will necessarily agree with all the decisions, but a good process will illuminate the debate, narrow the areas in dispute, and give all a fair opportunity to make their case.

Some elements of that process are also relevant to engagement with external stakeholders. It is good practice for consultation documents to articulate the issues, the available evidence, and the regulator's thinking. This assists stakeholders to set out what they agree and disagree with, and why. Mobile operators have their own expertise and often wide experience from participating in auctions in other countries. The regulator should take their points seriously, in some cases adjusting its analysis and in others giving reasons for rejecting stakeholder submissions. The reasoning can be detailed, both to provide a full explanation and in light of the litigation risk to a legal standard (in the UK) that includes taking due account of the merits, not just procedural concerns. However, there is not an expectation that the regulator will always reach consensus with stakeholders, who in any case usually hold divergent views as their interests are often in conflict. It is very rare that a regulatory decision is greeted with universal approval. The opposite is more common, as exemplified by the litigation discussed in Section 5.4 which included two appellants making opposing criticisms.

The UK's 2021 auction illustrated where bargaining and incrementalism could be part of the process. The initial phase was rational-comprehensive, with an innovative CCA design initially proposed in the December 2018 consultation that benefitted greatly from external expert advice on how to integrate the procurement of onerous coverage obligations (see Section 10.2). Then, bargaining entered the frame, as the government was in a negotiation process with mobile operators. They finally reached agreement in March 2020 on rural coverage extension (the Shared Rural Network), superseding the regulator's proposed coverage obligations.[17]

Taking coverage obligations out of the auction removed the key analytical rationale for a CCA. Therefore, the regulator proposed a different design using the SMRA format. So far, so rational-comprehensive for the auction design. The incrementalism was the extent to which the 2021 SMRA design was then refined by reference to the successful 2018 auction. On some specific issues, fresh analysis was needed (such as reserve prices). But for the rest, instead of a greenfield assessment from first principles, the analysis was largely in terms of similarities and incremental differences compared to circumstances in 2018. Some changes were made to the detailed rules, but the resulting auction design was very similar to that for the 2018 auction. Although different spectrum was being awarded, this incremental approach made sense in this case as there were many parallels. However, where circumstances are sufficiently different, an incrementalist approach can be risky.

The incrementalist approach is used more prevalently by some other regulators. For example, a horses-for-courses, rational-comprehensive approach is usual in the UK (and elsewhere, such as Australia, Austria, Canada, the Netherlands, Sweden, and the USA). But in Germany, for example, there is a different approach of sticking with a tried and trusted design in different circumstances, with only incremental modifications. Incrementalism carries risks if there is insufficient expertise to appreciate ramifications of the modifications. One illustration is the nine-month 2013 auction in Finland, referred to in previous chapters. It amended an established SMRA design used elsewhere in Scandinavia, with embarrassing consequences.[18] Similarly, while the design elements of Portugal's 2021 auction were not novel, an unfortunate – yet predictable – confluence of features led to world-record bidding duration (see Section 11.2 for details). When announcing its decision on the auction design, the regulator had forecast the auction would finish in January 2021 – in fact, bidding only ended in late October 2021.[19] The auction was heavily criticised, and some design flaws were pointed out during consultation. The moral of these stories is that *expertise matters*, even when seeking only to muddle through.

5.2 Coordination challenges for competition measures

In public policy decisions, is it better to have a single agency making decisions encompassing diverse aspects, or to coordinate across multiple public organisations? Taking the example of Australia, the process to set spectrum caps and set-aside in the 2021 auction was not integrated because decision-making was split between three organisations. The competition authority, the Australian Competition and Consumer Commission (ACCC), provided advice. The decision-making authority for competition measures resided with the relevant minister. The spectrum regulator, the Australian Communications and Media Authority (ACMA), then incorporated the caps and set-aside into the auction design and ran the auction.

In contrast, the independent regulator in the UK, Ofcom, analyses and determines the case for competition measures and also implements them in the auction design. Ofcom has expertise in competition analysis – for example, it is itself a competition authority for electronic communications, because the UK operates a concurrency regime for competition law, meaning that each sector regulator has jurisdiction in its industries, along with the general competition authority, the Competition and Markets Authority (CMA). In a number of other countries the spectrum regulator may not have the competition expertise to assess such issues. In Australia, due to legislative amendments, the involvement of the three public bodies was changed for later auctions, so that the decision would be made by the ACMA after consultation with the ACCC (and the minister only able to issue policy statements to be considered by the ACMA). The revisions to the Australian regime made it more similar to the UK's. A remaining difference is that the ACMA has to consult with the ACCC, whereas there is no corresponding requirement in the UK for Ofcom to take advice from the CMA.

Sequential versus simultaneous decisions

The nature of the linkages between decisions affects the challenges raised by a sequential approach to decisions, as in the old regime in Australia (analogously, when deciding whether to auction spectrum bands simultaneously or sequentially, demand linkages are a crucial consideration – see Section 7.4). One potential set of linkages is between decisions about competition measures and auction design. A rationale for imposing spectrum caps is to avoid auction outcomes that weaken downstream competition arising from strategic investment, an operator winning additional spectrum just to prevent its rival from acquiring it and being a stronger retail competitor. The incentive to engage in strategic investment can be affected by the choice of auction format. For example, due to different pricing rules, in the SMRA the strategic bidder pays a higher price for all the spectrum it acquires, whereas in the CCA the strategic investment can be less costly – and hence more attractive – as the higher price may only be for the additional spectrum. The auction format will often not be a deciding factor whether or not to impose a competition measure. But, if it is, there is the challenge of coordination across sequential decisions made by different agencies. Another possibility is the use of spectrum floors, flexible spectrum reservation as in the UK's 2013 auction. This type of competition measure involves more profound linkages between the competition assessment and the auction design. For example, the approach depends on the flexibility in the CCA format and may be hard to implement in other auction formats. Similarly, there can be risks of regulatory failures in implementing competition measures in the auction design – a specific example for Australia analysed in Section 9.3 is whether the reserve price for set-aside spectrum in the 2021 auction was higher or lower than the market price for unreserved spectrum. Such risks are relevant to deciding whether the competition measures are proportionate to impose in the first place.

Therefore, the relevant linkages affect the most appropriate sequencing of decisions between competition measures and auction design. However, a sequence of decisions by separate agencies may be hardwired into the construction of the regime, not case-by-case assessment. In many cases there is not a tight interaction between the decisions, with the appropriate competition measure not strongly affected by the selected auction design, and vice versa. But there are situations where simultaneous decisions would be much more appropriate – which the revised Australian regime has enabled.

Specialist expertise and democratic legitimacy

Competition assessment for spectrum auctions is based on a tailoring of standard antitrust analysis (see Chapter 9). In a large number of countries the competition authority is an independent agency, separated from political control. In Australia, the ACCC and the ACMA are well-established and respected independent agencies with authority to make decisions within their respective statutory remits. Yet in the old regime for spectrum auctions, the minister made decisions on competition measures. This contrast is interesting, especially as agencies with specialist expertise are generally better suited to make more technocratic decisions like spectrum caps or set-aside. The direct democratic legitimacy that such agencies lack, compared to politicians, is less of a concern than for broader social or public value questions like mobile coverage, which is discussed later in this chapter. The rationale for the legislative changes for the revised regime in Australia explained that 'the Minister will have less involvement in day-to-day spectrum management decisions that are more properly the responsibility of the regulator'. It also noted that the ACMA's decision-making authority on competition measures was part of 'granting ACMA greater independence and discretion in administrative processes'.[20]

The old Australian regime fits with a broader historical theme of the way spectrum policy is often perceived, reflecting its origins in command-and-control regulation, with the role of markets only being grafted on later. Typically the spectrum regulator was initially part of a political ministry, and this remains the case in many countries (and applied in the UK until 2003). By contrast, in most countries there is a longer history of competition authorities being more independent agencies, reflecting the framing of antitrust and mergers as more technocratic and non-political (with important exceptions such as media mergers that often involve ministers in decision-making). While the most suitable approach depends on the country context, there are benefits in technocratic decisions being made by agencies with the right expertise.

5.3 The political economy of extending coverage

Insufficient or patchy coverage, especially in less densely populated areas, is a source of major public concern common to most countries. It reflects the importance of mobile communications to everyday life including the delivery of public services. Improved mobile coverage yields broad societal benefits but also incurs additional costs of network provision. Mobile coverage therefore combines both political and economic questions. This section first assesses the balance between market and regulatory failures in extending mobile coverage. Then it examines who is best placed to address this policy problem.

Coverage obligations in auctions: risks of market and regulatory failures

Insufficient coverage can be characterised as a market failure, especially with the inclusion of broader social value in the analytical framework, as explained in Section 4.1. For example, improved mobile coverage can: provide a safety net for emergency situations such as car breakdown or a medical emergency; increase social capital (value created by social relationships); promote sustainability of rural communities; and support improved provision of public services such as technology-driven solutions in healthcare.[21] The extent of coverage that is commercially attractive for mobile network operators to provide, even where coverage is an important dimension of competition between them, falls short of public expectations. It is usually below the coverage level that maximises public value (although this also depends on costs, a key point that we will come to).

One policy instrument is direct procurement using government funding to obtain the desired level of mobile coverage. This can involve targeted funds, such as in Ghana, New Zealand, and Tunisia. Or there can be competitive tendering, as for universal service procurement auctions in the USA.[22] Another example is that the Mexican government tendered for coverage improvements in 2016, offering use of the valuable 700 MHz band for a new, wholesale-only shared network, Red Compartida. The requirement of the operator winning the tender, Altán, was to achieve 92.2 per cent population coverage by 2024.[23] A further approach is for the government to reach agreement with mobile operators to extend mobile coverage, either with financial compensation or through other measures of value to operators (such as favourable variation in licence conditions), such as in France, Peru, and the UK.[24]

A different policy instrument, commonly used throughout the world, is procurement through coverage obligations on mobile operators included as licence conditions for spectrum in auctions. Such obligations generally attract widespread public and cross-party political support, though often resistance from mobile operators. In the public debate during the policy development phase, there is interest in the headline features, such as the percentage of the premises, population, or landmass to which the obligations plan to extend coverage. Examples of variation in such headline obligations in the UK's high-stakes auctions are shown in the last column of Figure 5.3. All five licences awarded in the 2000 auction included an obligation for 3G coverage to at least 80 per cent of the population. In the 2013 auction there was one obligation for 4G indoor coverage to 98 per cent of premises. The obligations in the final row of Figure 5.3, achieved through direct procurement outside of an auction, were for 95 per cent coverage of UK landmass.

However, beyond the headline, the devil is in the detail for effective implementation and meaningful service delivery to mobile consumers. Crucial details include the technical engineering description of the quality of coverage to be provided, and sanctions for breaches of the obligations. Mobile coverage is not a simple binary concept and has various spectrum engineering dimensions. Examples are the probability of receiving a mobile signal, the ability to make just telephone calls or access data services, the speed of data services considered to be sufficient for good quality coverage, the contiguity or patchiness of outdoor coverage, and the extent of coverage indoors in homes and offices such as differences between reaching locations that are shallow or deep indoors.

An indication of these complexities and how the headline level of the obligation is far from a complete picture is provided by the obligation in the 2013 auction. The headline was 98 per cent indoor coverage: 'mobile broadband service for indoor reception to users in an area within which 98 per cent of the UK population live'.[25] However, the technical requirements in the licence condition formally specifying the obligation were about outdoor signal strength, not indoors. This was due to

Figure 5.3. Coverage obligations in the UK's high-stakes auctions including headline levels

Auction	Number of obligations	Headline level of obligations
2000	All 5 licences	80% population coverage of 3G by the end of 2007
2013	1 obligation	98% of premises with indoors coverage of 4G by the end of 2017 (Also: at least 95% in each nation: England, Northern Ireland, Scotland, and Wales)
2018	No obligations in auction	
2021	No obligations in auction, because superseded by the Shared Rural Network (SRN), a 2020 government agreement with all four mobile operators for 95% landmass coverage of 4G by the end of 2025	

Source: Author from Ofcom auction documents.

complications in verifying indoor coverage, which depends on the building materials and structure such as the thickness of walls. As explained by the regulator:

> In practice, this means that in many premises a good service will be available in all, or a wide range of interior locations, although reception is likely to be best at locations closest to the exterior of the building. In some cases, where the style of construction of the building is more challenging, the service may only be available in a limited range of indoor locations, for example close to windows. We recognise, however, that in a few cases where buildings both are in difficult-to-serve locations and have challenging construction types, it may be impossible to receive a 2Mbps indoor mobile broadband service.[26]

The consequence of the disparity between the headline and the detailed technical requirements was that the obligation did not guarantee the headline level of indoor coverage in all premises in the 98 per cent coverage area. Nor did it ensure mobile coverage deep indoors for these buildings.

Therefore, although attention being focused on the headline feature is understandable, it is only the tip of the iceberg and can give a false impression of the realised consumer experience. The complexity of the technical detail is a serious barrier to more precise public debate, despite the crucial implications for the coverage experienced by people in practice. It exacerbates the well-established behavioural bias of limited attention only on salient features, such as simpler headlines.[27] This situation of complexity and limited attention is a recipe for risks of regulatory failure from *overpromising* and *under-delivering*. The first reason is that the headline features of obligations could give a false impression of the realised consumer experience, such as the 2013 obligation not in fact providing 98 per cent indoor coverage. The relevant operator (Telefónica) complied with the obligation by the deadline of the end of 2017. It had more extensive 4G coverage than other operators, yet the regulator's measurement in 2018 was that it provided good quality indoor coverage to only 95 per cent of premises (with even lower coverage deeper indoors).[28] Another example is the obligation on all operators from the 2000 auction which did not specify a specific quality of 3G service for 80 per cent population coverage. It left open the possibility that compliance could be achieved by 'thin and crispy' coverage, instead of 'deep pan' coverage offering more meaningful 3G services to consumers. This was especially relevant because a downturn in the stock market meant that the operators were even more strongly incentivised than usual to minimise their costs of meeting the obligation.

A second source of regulatory failure is excessive attention on headlines that are not always tightly related to benefits. For example, obligations are sometimes specified in terms of landmass coverage (as in the 2020 agreement), but benefits can differ markedly depending on the way that coverage level is achieved. Mobile users are likely to gain greater benefits from operators achieving contiguous coverage by removing 'not-spots' in populated areas that have patchy coverage, compared to extending coverage to remote areas that people rarely visit.

Another risk is that headlines can be maintained at higher levels, attracting more favourable publicity, through watering down the technical specification of the required quality of coverage that is only visible to those with specialist knowledge. The wider public debate tends to focus on the benefits of more extensive coverage, but balancing benefits against costs is of great importance in the regulatory process to justify the obligations and engage with the concerns of the operators who expect to bear those costs. Hence, reducing the technical specification, and thereby lowering the cost to operators, can diminish the strength of their opposition to the obligations.

A fourth source of regulatory failure is the behavioural bias of treating headline policy development as the focus of public and political attention, disconnected from subsequent implementation which is left as boring details for the technocrats. An example is the methodology to measure operators' 3G coverage levels and compliance with the 2000 auction obligations not being defined at the time. It was in fact only developed many years later and finalised in 2007, less than a year before the deadline for achieving compliance.[29] In assessing compliance, there can be aligned interests of all parties for the targets to be seen to be met: mobile operators to avoid sanctions and public organisations to demonstrate success. There is a risk of a 'wilful blindness' about whether reported 'success' masks measurement problems and gaming, or actually achieves the desired consumer experience of improved mobile coverage.[30]

These endemic challenges of communication and regulatory failure do not necessarily mean that coverage obligations fail to deliver meaningful public value. But they point to significant risks of less than complete effectiveness (under-delivery) and unintended consequences. The best ways to manage the regulatory failure risks depend on the characteristics of the decision-maker for coverage obligations. The question of decision-making roles for political ministries and independent regulators is considered next.

Decision-making roles: technocratic issues and public value

The boundaries between the respective remits of ministries and regulators are usually not defined precisely, and there is typically overlap of policymaking authority. For example, Ofcom's duties include 'the availability throughout the United Kingdom of a wide range of electronic communications services'[31] so that it can be the independent regulator deciding the coverage obligation, as in the 2013 auction. The relevant ministry is also active, reflecting the public importance of coverage concerns and perhaps also under-delivery from coverage obligations in auctions. For example, there was direct procurement in the form of agreements between the UK government and mobile operators to extend coverage in 2010, 2014, and 2020:

- In 2010, the 3G coverage obligations were increased from the 80 per cent level in the 2000 auction up to 90 per cent of the population. This was part of a package of measures, some of which enhanced the value of operators' licences as compensation, such as changing the licences awarded in 2000 from having a fixed term to indefinite duration.

- In 2014, new obligations were introduced for voice and text coverage for each operator across 90 per cent of the UK landmass by the end of 2017.[32]
- The 2020 agreement for a Shared Rural Network was for obligations to achieve 95 per cent landmass coverage for 4G services by the end of 2025. The mobile operators agreed to invest to remove nearly all 'partial not-spots' (where some but not all network operators provided coverage), and the government to provide more than £500 million to fund the elimination of 'total not-spots' (where no operator had good quality coverage).

In all three cases, the role of the independent regulator was to advise the government during the negotiations, implement the agreed coverage obligations through conditions in spectrum licences, and enforce the obligations.[33] For example, the regulator's advice included technical details about the obligations, such as the quality of service that constitutes good coverage (which it assessed through evidence obtained in a programme of research). For the 2020 agreement, Ofcom had a further type of engagement in the process. The initial government expectations were that Ofcom would include coverage obligations in the 5G auction (ultimately held in 2021).[34] The government had a stated political objective of 95 per cent landmass coverage, which derived from the Conservative Party's election manifesto.[35] In 2018, Ofcom proposed two coverage obligations but for only 90 per cent landmass coverage, raising the question of policy consistency.[36] This sparked the negotiation process between the government and the operators. The government was looking to achieve its 95 per cent target. Possible motivations of the operators to enter negotiations were a desire to reach a settlement with the government to resolve the 'running sore' of the coverage problem at least for a period of time, and to establish the principle of government funding for coverage extension. The operators also strongly preferred a different auction design than in Ofcom's 2018 proposals.

Ofcom therefore contributed to the government's bargaining position as a by-product of its proposed design to integrate coverage obligations into the auction (explained in Section 10.2), because it was disliked with varying degrees of intensity by the operators. The key source of operators' concern was Ofcom's proposal to use the CCA format (which, in particular, operators claimed would expose them to price driving – for views on both sides of this question see the discussion of under-confidence in the CCA in the first section of this chapter). The operators knew that agreeing a coverage deal with the government would remove the key analytical rationale for the CCA, and so lead the regulator to switch to a different auction design using the SMRA format that they much preferred. This is what happened.

When thinking about the best policy instrument to achieve public value of improved mobile coverage, there are superficial political attractions for governments of coverage obligations in spectrum auctions:

- In the blame game, the government can claim credit from directing the regulator to enhance mobile coverage, and leave the messy wrangling with the operators over complex implementation details to the technocrats in the regulator.
- The operators want valuable spectrum from the auction which induces them to take on the obligation without the need for explicit government funding.
- The implicit funding through reduced revenue from the auction due to the costs of the obligation is less obvious. It may not be transparent at all, depending on how the obligations are integrated into the auction design.[37]

However, the 2020 coverage agreement illustrates some of the advantages of the alternative policy instrument of direct procurement:

- The decision-maker has political legitimacy to adjudicate appropriate levels of coverage and strike a balance between benefits and costs, avoiding policy inconsistency from independent agencies.
- The risk of distorting the efficient allocation of spectrum and/or the obligation is avoided. This can arise from including the obligation in the auction, because the most efficient, lowest cost provider of the coverage obligation may not have the highest value for the spectrum.
- In this case mobile phone users benefitted from the government agreement setting the level of the obligation at a much higher level than the regulator. As well as being 95 not 90 per cent, the agreement included all four operators whereas the regulator's proposals were for obligations on only two operators. The agreement included elimination of total not-spots, whereas the regulator's proposals focused on mitigating partial not-spots (which it considered had a more favourable cost-benefit balance).
- In part, this difference could have been because the government judged there to be larger benefits of extended coverage than the regulator believed it could justify.
- The agreement also achieved lower costs from the shared rural network between all four operators than the regulator could have ensured (as it was not within the regulator's powers to mandate such network sharing).

Risks of regulatory failure remain. The headline of the 2020 agreement was 95 per cent landmass coverage by the end of 2025.[38] But the detailed obligations were different: each operator to provide 88 per cent coverage by 30 June 2024, and 90 per cent by 30 June 2026, subject to certain conditions including the provision of government funding.[39] There was engineering modelling analysis linking the two, suggesting that each operator achieving 90 per cent would lead to collective achievement of 95 per cent coverage due to some non-overlapping operator coverage areas.[40] But what would actually be achieved on the ground remained to be seen. Another point is that the obligations were built around 4G, not the latest 5G technology that may be more in line with public expectations by the mid-2020s.

A further question is the cost-benefit balance for 95 per cent landmass coverage. The reason why Ofcom's 2018 proposals were for obligations at the lower level of 90 per cent was it considered that the incremental benefits of going beyond 90 per cent were unlikely to justify the incremental costs. Specifically, it took the plausible view that incremental benefits are expected to decline with higher coverage levels, because areas successively added have lower population density and are more remote. On the other hand, for similar reasons, it estimated that incremental costs would increase with higher coverage levels.[41] The regulator asked itself a break-even question of whether it was likely that the incremental benefits would match or exceed the estimated costs. This is an example of structuring the required judgement in an impact assessment to assist reasoned decisions, neither gut feel nor spurious quantification (see Section 6.1).

The use of a shared network in the agreement lowered costs compared to these estimates. Also, different views can reasonably be taken about the scale of benefits as they involve much policy judgement. These considerations could change the incremental cost-benefit balance for greater landmass coverage compared to the regulator's view. Even if so, incremental public value per person living in or visiting remote rural areas would need to be large to justify the higher incremental costs of the last few percentage points up to 95 per cent landmass coverage. Given the origin of the political target, there was a risk of retrofit by the government, a practice sometimes labelled as 'policy-based evidence making' (as a contrast to the rational-comprehensive approach of evidence-based policymaking). More positively, the 2020 agreement seemed to avoid some sources of regulatory failure. The required quality of service for good coverage followed the regulator's advice.[42] Also, a detailed compliance methodology was specified at the time of the agreement.[43] Measurement problems and gaming to achieve the target remained as future compliance questions.

Overall, coverage obligations in auctions implemented by the regulator can be an appropriate policy instrument. However, sometimes the hard slog of direct procurement by a political ministry with democratic legitimacy can achieve higher public value at lower cost. Whichever policy instrument is chosen, risks of regulatory failure from communication challenges are hard to avoid, due to complexity and limited attention. But they can be mitigated by joining up expert technocratic advice on implementation challenges with policy development, using appropriate technical specifications, and aligning headline requirements with beneficial consumer experiences on the ground.

5.4 Litigation: the expert's role in court battles

Policy is developed for all major spectrum auctions in the UK in the shadow of litigation threats from mobile operators dissatisfied with the balance being struck by the regulator. For example, before the 2013 auction the government took steps to corral operators not to litigate and delay that auction. An appeal process was initiated before the 2021 auction, although it was not taken forward after the deferral of the auction arising from the Covid-19 pandemic. The 2018 auction was, however, delayed by around four months due to litigation at both the High Court and the Court of Appeal of Ofcom's decisions on spectrum caps. One mobile operator (EE) challenged a cap as being too stringent. The appeal by another operator (H3G) was the opposite, that the cap was too lax. The episode ended happily for the regulator as the court judgment decisively supported its reasoning and decisions on spectrum caps.[44]

In UK court proceedings there are witnesses of *fact*, who report events or information within their own knowledge, and *expert* witnesses who provide their professional opinion. In some proceedings, experts are appointed by the court or jointly by both claimants and defendant. However, in regulatory civil litigation, the various experts are employed by each side. The experts for the claimants set out reasoning supporting the cases being put forward to challenge the regulator's decision, to which the expert for the regulator responds. It has been the consistent practice of Ofcom mostly to use as experts its own internal senior specialists who worked on the contested decision.[45] There is regular litigation of Ofcom decisions, so that I had the dubious pleasure of becoming experienced as an expert witness in a range of cases, including the litigation of spectrum caps. This particular High Court case involved only written expert evidence, with no oral cross-examination (unlike cases in the specialist tribunal, the Competition Appeal Tribunal, which hears many other regulatory cases). Regardless of who pays expert witnesses, they have a duty to assist the court that overrides any obligation to their clients.[46] Their role is to provide unbiased, reasoned analysis. They make a statement of truth, including a signed declaration that their report represents their 'true and complete professional opinions'.[47] Some courts seem to allow more leeway than others in strict adherence to these responsibilities of the expert.

For an expert witness focusing on public value with no commercial interests, this set-up means that attributes which are often undervalued or even regarded as naive in other contexts are especially important, such as balance, neutrality, perspective, calmness, and patience. The overall court process is adversarial, but an expert who is a truth-seeker proactively wishes to help the court, not advocate for a particular view. If good arguments are made against a point in the decision, they should be acknowledged. Issues involve trade-offs, so there are arguments and evidence on both sides of the debate. Moreover, in litigation it is inevitable that more arguable points will often be the focus of the claimants as that can increase their chances of success. If the regulator's decision is soundly based, there will be reasoning to counterbalance the challenge. If not, then it may be right for the point to be overturned (although this will generally also depend on other factors, such as its importance to the overall conclusion).

Section 3.3 described how experts can help the regulator reach decisions through drawing out intuition, explaining interaction between different parts of the analysis, and highlighting points that matter the most. There is a parallel with expert witnesses fulfilling their duty to assist the court. One of the more helpful tasks is to clarify areas of agreement as well as disagreement, instead of point scoring against the opposition. Experts can bend over backwards to characterise fairly the arguments to which they are responding, or even put forward a more coherent version: a 'steel man' not a 'straw man'.[48] This facilitates the court sorting the 'wheat' of the points it needs to decide from the 'chaff' of the often voluminous detail in the litigation documents.

Based on my involvement in a range of regulatory litigation, I have observed an apparent market failure in the employment of experts arising from behavioural biases of the client's emotions. Many clients seem to favour witnesses that they see as fighting their corner, advocating their case. Yet the relevant audience deciding the judgment is the court. Advocacy from experts is rather less effective and influential with the court compared to the neutral approach just described. Experts can strengthen their credibility and independence by going out of their way to present both sides of the story and to acknowledge good points made by opponents. Experts taking this approach are only likely to have a winning strategy where their case is sound. But if not, there may be no winning strategy. Nor perhaps should there be, when we are seekers after truth.

A degree of humility is warranted as the quality of the decision and the merits of the legal challenge matter rather more to the conclusion than the performance of the experts on each side. In this litigation, the regulator's decision being defended was thorough, careful, and nuanced, and whether affected by expert evidence or not, it survived the challenges.[49] The regulator's decisions on spectrum caps for the 2018 auction were therefore validated. More generally, this type of accountability strengthened the regulator's reputation for competition analysis in auction design, one of its core competencies. To the extent it affects the outcome, being persuasive as an expert witness in these types of court proceedings is less about defensive advocacy (which is instead the role of the lawyers) than balanced, dispassionate, and constructive analysis. At the heart of experts' effectiveness is adapting from the prior policy debate to understand that the essence of their role in this different legal arena is assisting the court to reach its decision.

5.5 Wider lessons for public policy

This chapter has drawn on practical experiences of decision-making processes in spectrum auctions on the topics of auction design, competition measures, and mobile coverage. The examples illustrate cross-cutting policymaking challenges for the role of experts in mitigating behavioural biases, playing the blame game, allocating decision-making authority, and coordinating between organisations. Such challenges arise in public policy processes far beyond spectrum auctions.

For example, experts can strengthen their role by engaging in the communication challenge of influencing pragmatic and political processes for public policy development. Effectiveness in market design depends on combining deep understanding of scholarly research with practical know-how and an eclectic, inclusive perspective to grapple with wider values and policy challenges in the public sphere. Policymakers have their own priorities and preoccupations, and effective experts *assist* their decision-making, and do not supplant them. Similarly, albeit in the rather different context of litigation, experts interested in public value can be most effective by adapting to different demands of the legal arena, fulfilling their role to assist the court and shed light (not heat) on the debate.

In turn, decision-makers can benefit from paying attention to effective experts. Spectrum auctions provide ample examples of why experts can be important to good policymaking. When incrementalism has been adopted for particular auction designs, it has led on occasion to bad experiences – even when muddling through, *sufficient* expertise is needed to appreciate the risks and avoid embarrassing failure. Such examples emphasise that policymakers shutting out expertise can be problematic, and taking notice of well-chosen expert advice can pay dividends.

The UK experience also shows that policy tools that seem *convenient* are not necessarily the most effective. Coverage obligations in spectrum auctions seem an easy policy vehicle to achieve improvements in mobile coverage. But there has been a chequered experience in the UK. Direct procurement by a political ministry has grown in importance over time, and has advantages. The 2020 agreement between the government and mobile operators illustrated how direct procurement can achieve greater benefits (such as higher coverage levels by more operators, and avoiding risks of distorting the spectrum allocation in the auction) and lower costs (improved cost efficiency through network sharing).

The bounded rationality of public decision-making is explored in the developing field of study of behavioural public administration. Spectrum auctions provide examples of *biases* in decision-making processes for both design choices and coverage obligations. The biases arose from overconfidence or focus on headlines where complications were beneath the surface. Or conversely from under-confidence or limited attention where complexity obscured effectiveness. For example, there can be overconfidence in the SMRA format, as its mechanics are intuitive, whereas strategic complexities for bidders are beneath the surface. In contrast, the CCA design can suffer from under-confidence due to the heavy machinery of its complicated mechanics masking its suitability in relevant circumstances (such as package bidding allowing bidders to express large synergies in their values for spectrum in the auction). Biases in determining target levels for increased mobile coverage can arise from excessive focus on headlines and limited attention on complex engineering details that affect the quality of services experienced by the public. There are practical examples of overpromising and under-delivering. Behavioural features are endemic to human decision-making when a need for judgement is paramount. But recognising when biases are present can assist to mitigate some of the worrying implications.

There are contrasting examples of reputation management and the *blame game* in public policy, which are interrelated with behavioural biases. Public credit can be earned from headline coverage requirements that sound more ambitious, contributing to the risk of overpromising. Conversely, the episode of media reporting of the 2013 auction revenue falling £1 billion below the pre-auction forecast showed politicians being an unjustified blame magnet – the forecast and design decisions were made by independent public bodies, and revenue-raising was not an auction objective. The media focus on revenue in reporting about auctions is itself a bias towards simpler headlines. Limited attention is paid to the greater complexity of economic efficiency and public value outcomes, which are nevertheless often far more important.

There are choices to be made for the allocation of decision-making authority between public organisations. As shown for the examples of competition and coverage decisions in spectrum auctions, there is a balance to be struck between *values* and *expertise*. The regulator has relevant specialist expertise for both, but the nature of values in play differs. Decisions on competition measures like spectrum caps and reservations are more technocratic. As such, there are benefits of independent regulators making these choices instead of political ministries (a change that occurred in Australia in 2021), whereas broader public values make the democratic legitimacy of politicians more central to judgements about socially desirable mobile coverage.

Overall, the successes of spectrum auctions show the *benefits* of markets. But the examples of failures also demonstrate the *risks*. Well-judged use of market design expertise can help to avoid embarrassing failures. It can substantially increase the chances of achieving successful outcomes to benefit the public, industry, and the economy.

Notes

1 For example, Banuri, Dercon, and Gauri (2019) find evidence among UK government and World Bank policy professionals of confirmation bias driven by ideological predisposition.

2 Wilson (1989), and Wegrich (2019).

3 Koop and Lodge (2014).

4 For example, in the UK the Scientific Advisory Group for Emergencies, https://www.gov.uk/government/organisations/scientific-advisory-group-for-emergencies.

5 For national licences, Koutroumpis and Cave (2018) report a much higher average price for 'CCA with core pricing' than for 'standard SMRA' (although 'SMRA with augmented switching' is much closer). Ihle, Marsden, and Traber (2018) find significantly higher prices with the CCA for low-frequency spectrum (sub-1 GHz) but not for capacity spectrum at higher frequencies.

6 Malmendier and Taylor (2015), and for public managers, Battaglio et al. (2019).

7 See the foreword by Evan Kwerel in Milgrom (2004).

8 See the cartoon by Randy Glasbergen, https://perma.cc/YTX9-4WQ3.

9 Hood (2002).

10 See Reuters 'Mired in disputes, Portugal's 5G auction drags on with no end in sight', 22 October 2021, https://www.reuters.com/business/media-telecom/mired-disputes-portugals-5g-auction-drags-with-no-end-sight-2021-10-22/.

11 A key problem with the design in New Zealand was that the licences were awarded at the same time but in separate, unlinked auctions that prevented bidders from taking account of them being substitutes or complements – see Milgrom (2004, p.12). In contrast, the CCA and SMRA formats award licences in a simultaneous process.

12 There is also no gain from bidding above full value with a second-price rule, because this only increases a bidder's chances of winning when it is loss-making. An illustrative example is a bidder with a value of 100, winning by making a bid of 120. Either the highest losing bid is less

than 100, such as 80, in which case it would have won with a bid of 100 and paid the same price of 80. Or the highest losing bid is more than 100, such as 110, in which case it pays a price of 110 which is higher than its value of 100 leading to a loss of 10.

13 National Audit Office (2014, p.23).

14 Office of Budget Responsibility (2012).

15 See Tim Harford 'Don't blame Ofcom if the 4G price isn't right', 20 February 2013, https://perma.cc/69DB-GLU9.

16 See the cartoon in The Guardian 'Kipper Williams on the disappointing 4G auction', 21 February 2013, https://perma.cc/UDS3-KLEU.

17 Department for Digital, Culture, Media & Sport (2020), and Shared Rural Network, https://srn.org.uk/.

18 The design problem in Finland related to bid withdrawals – see DotEcon (2019, pp.48–49).

19 See ANACOM 'ANACOM announces conditions of the auction for 5G and other relevant bands', 12 November 2020, https://perma.cc/R5JV-5CZG.

20 Australian Parliament (2020, pp.1 and 32).

21 Ofcom (2018b, paragraphs A11.57–A11.72).

22 Kwerel et al. (2017, section 3).

23 The Mexican Government's website for the shared network is at https://www.gob.mx/promtel/acciones-y-programas/red-compartida-255015, and the operator's at https://perma.cc/4HVB-V9D3.

24 See GSMA 'Expanding Mobile Coverage – Partnerships for a Connected Future', https://perma.cc/J7C3-FR25.

25 Ofcom (2012b, paragraph 1.22).

26 Ofcom (2012b, paragraph 5.31).

27 DellaVigna (2009, section 4.2).

28 Ofcom (2018c, figure 6).

29 Ofcom (2007a).

30 Bevan and Hood (2006).

31 Communications Act (2003, section 3(2)(b)).

32 Department for Culture, Media & Sport (2017b).

33 For the 2010 agreement, Ofcom was directed by the Minister for Culture, Communications and Creative Industries (2010), and compliance is set out by Ofcom (2013). For the obligations agreed in 2014 and 2020, see Ofcom (2020d). The government retained a role in enforcement of the 2020 obligations due to the provision of public funding.

[34] Department for Digital, Culture, Media & Sport (2019).

[35] The Conservative and Unionist Party Manifesto (2017, p.78).

[36] Ofcom (2018b).

[37] For example, if the obligation is pre-attached to spectrum and there is other spectrum in the same band unencumbered by an obligation, the difference in bids by a bidder can indicate its expected cost of the obligation. But if obligations are attached to all spectrum in the band, the cost is not transparent.

[38] Department for Digital, Culture, Media & Sport (2020).

[39] Ofcom (2020d).

[40] See Shared Rural Network 'Forecast Coverage Improvements by Region', https://srn.org.uk/forecast-coverage-improvements/.

[41] For example, estimated cost of £108–139 million for the increment of 90% to 92%, compared to £85–107 million for the increment of 88% to 90% – see Ofcom (2018b, annex 12).

[42] The coverage requirement was defined in the 2020 obligations as 'an electronic communications network that provides with a confidence level of more than 95% a mobile telecommunications service to users (i) with a sustained downlink speed of not less than 2 megabits per second, and (ii) on which 90 second voice calls can be made without interruption' — see the definition of 'Required Service' in operator licences for spectrum in the 1800 MHz band, such as Ofcom (2020e, p.6).

[43] Ofcom (2020b).

[44] High Court (2017); subsequently, the Court of Appeal refused permission to appeal to H3G.

[45] This has given rise to claims that Ofcom witnesses should not be regarded as experts, which the courts have generally rejected. An example is Competition Appeal Tribunal (2014, paragraph 72): 'Mr Myers was responsible for overseeing the economic analysis in the Determination, and to that extent his evidence was in part as a witness of fact.... In addition, however, Mr Myers gave evidence also as an expert economist. It was put to him that he was appearing as the "champion of Ofcom" to defend the Determination but Mr Myers denied this and said that he was very conscious of his duty to the Tribunal. We accept that answer and do not find that the fact that he was employed by Ofcom impeded his objectivity.'

[46] See Ministry of Justice 'Rules and Practice Directions: Part 35 – Experts and Assessors, Rule 35.3', https://perma.cc/SH6Z-3E8Y.

[47] See The Academy of Experts 'Expert Declarations', https://perma.cc/S35L-T9WW.

[48] See Issuepedia 'Steel man' https://perma.cc/L4HB-GLFZ.

[49] Examples from High Court (2017, paragraphs 155 and 183) are: 'the reasoning in the Decision for the 37% cap was good and solid reasoning on its own merits'; and 'Ofcom had a perfectly sensible and rational basis for ex ante regulation.'

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PART II

Designing and implementing spectrum auctions

Once the politics and principles of going ahead with spectrum auctions are settled, many design and implementation decisions remain to be made. The details are often highly consequential for the success of the auctions. Part II of the book assumes that a choice to go ahead with auctioning spectrum has been made, and works through the multiple implications and decisions that follow. It covers the issues from start to finish, and draws on ideas already introduced in Chapters 3 and 4. A set of tailored analytical frameworks are progressively developed. Evidence is analysed from examples including the detailed case study of UK high-stakes auctions.

The foundations for getting auctions under way often need to be prepared well in advance, and Chapter 6 considers where the spectrum to be auctioned comes from, under what licence terms, and with what timing. Chapters 7 and 8 analyse design choices such as the hierarchy of objectives, reserve prices, division of spectrum into lots, auction format, and detailed rules. Chapter 9 assesses effects on downstream competition, and Chapter 10 provides examples of innovative auction designs for each of competition measures and coverage obligations. Chapter 11 covers the running of the auctions themselves, analysing the bidding and outcomes in UK auctions to draw out future lessons, and addressing practical implementation questions. The Afterword provides a few final reflections.

6. Laying foundations before the auction

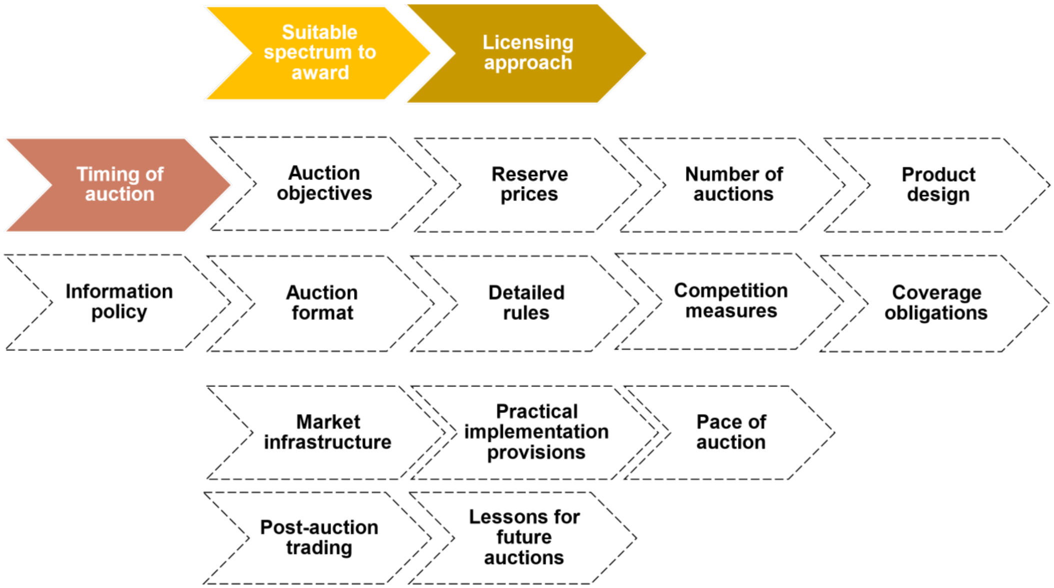
Summary

- Obtaining suitable radio spectrum to auction can require a policy decision to change from previous uses of a band, supported by an impact assessment finding sufficient benefits to justify the costs of clearing incumbent users from the band. A practical example is the UK's 2014 decision to change use of the 700 MHz band from TV broadcasting to mobile broadband (and it was ultimately awarded in the 2021 auction).
- Impact assessments, however, are frequently misused. They can be underused, making the perfect the enemy of the good, where economic analysis is imperfect or incomplete but can still provide valuable insights. Alternatively, the impact assessment approach can be overused, with an economic perspective allowed to crowd out other valid points of view about public value, or including complex detail that can obscure policy judgement.
- Spectrum is a common pool resource, prone to excessive use depleting the scarce resource effectively available, due to harmful interference between competing radio signals. Licensing spectrum is a response to this market failure risk. However, market failure should be balanced with the risk of regulatory failure from imposing too many licensing restrictions.
- There are many spectrum licensing approaches, from licence exemption to exclusive licences. Picking a licensing model can be seen as a market design choice that changes the spectrum market between free entry, sharing, or oligopolistic competition.
- On the timing of the auction, the regulator must strike a balance. It should avoid holding the award too soon, before demand for the spectrum has crystallised. But the auction should also not be too late, because that can delay when the spectrum is brought into productive use for the benefit of the public, industry, and the economy.

How to cite this book chapter:

Myers, Geoffrey (2023) *Spectrum Auctions: Designing markets to benefit the public, industry and the economy*, London: LSE Press, pp. 95–113. https://doi.org/10.31389/lsepress.spa.f. License: CC BY-NC-ND 4.0

Figure 6.1. Auction decisions assessed in Chapter 6



Source: Author.

In the modern world, radio spectrum that is desirable for providing mobile services rarely lies unused. So a starting point is to examine in the first section where suitable spectrum to award can come from – see the first highlighted step in Figure 6.1. The analytical tools used to analyse policy decisions for changes in spectrum use in economic and social terms are impact assessments, which have both strengths and limitations. The second section analyses the licensing approach for the spectrum as a significant market design choice with far-reaching implications. Different approaches can be taken to balance the risks of market failure arising from radio interference and regulatory failure from imposing excessive restrictions. If exclusive licences are chosen, then the licensees' property rights make usage of the resource excludable, the solution generally adopted for mobile spectrum. Another approach is to exempt spectrum users from the need to obtain a licence, instead using limits on transmission power to alleviate interference risks, as for wi-fi. Between these options, there also lies a range of licensing models for spectrum sharing. Timing issues about setting the auction date and fixing the duration of the licence are also outlined in the last part of the chapter.

6.1 Band clearance and use or misuse of impact assessments

Increasing mobile operators' access to spectrum reduces their network costs, by enabling them to increase capacity at their existing cell sites. It reduces the need to build more base stations to meet rapidly growing demand for data services. The greater ease of adding capacity using additional spectrum can also intensify competition between operators. Empirically, it has been found that retail prices are lower with a larger amount of mobile spectrum in a country, in both the developing and developed world.[1] Operators and commentators often complain that regulators cause delays in making spectrum available for mobile use. Countries in some continents have been criticised for awarding much less spectrum than others, including in Africa and Latin America.[2]

Before a suitable spectrum band can be awarded for mobile use, it has to become available. Unless it is 'virgin' spectrum that has not previously been deployed for wireless services, there are incumbent users. For example, the 4G and 5G capacity spectrum in the UK's 2018 auction (the 2.3 GHz and 3.4–3.6 GHz bands) were released for award to mobile operators by the Ministry of Defence, a large public sector user of spectrum. Or there may be private sector incumbents, such as for satellite earth stations or wireless capacity links in the 3.6–3.8 GHz band which were included in the UK's 2021 auction.

Market mechanisms or impact assessments for change-of-use policy decisions

An example worth discussing in greater detail concerns the other spectrum in that 2021 auction, the 700 MHz band. Previously it was used for terrestrial television broadcasting, both for private sector commercial interests and public service broadcasting. Technology and market developments can change the pattern of optimal use of spectrum over time. Broadcasting is essentially a 'one to many' transmission technology, meaning that the same broadcast signals can be received by many different consumers. So adding another consumer within the coverage footprint does not require additional network capacity. The move from analogue to digital broadcasting technology increased spectral efficiency, so less spectrum was needed to deliver the same terrestrial broadcasting capacity. In addition, the popularity of alternative distribution networks for video content, such as satellite and online, lowered the incremental value of spectrum for terrestrial broadcasting.[3] This tended to reduce the demand for spectrum from terrestrial broadcasters, even with expansion in the number of television channels.

Mobile networks use 'one-to-one' technology – e.g. a mobile telephone call connects two specific people, the caller and call recipient, or consumers browsing the internet on their phones engage individually with a website. To meet the growth in demand for mobile data, operators need to provide additional capacity, which can be done in three broad ways: building more base stations to use the spectrum more intensively (network densification); introducing more spectrally efficient technology (such as 5G compared to 4G), or using more spectrum. All three tend to be needed to meet the rapid and persistent growth in mobile data (which was 44 per cent per year on average in the UK between 2014 and 2019).[4] Therefore, there has been a large increase in the demand for spectrum from mobile operators.

One policy question that arises for the regulator is about the 'ends' – what the best use is of the spectrum band. Another relates to the 'means' – how the most desirable outcome is to be achieved. Just as for the award itself, there can be both administrative and market-based approaches to these questions. Market mechanisms for clearance and change of use of a spectrum band are possible in the right circumstances, addressing both the ends and means of optimal use. The reasoning is that, if new users have higher value for the spectrum than incumbents, there are opportunities for market transactions that are both profitable and efficiency-enhancing. One possibility is through bilateral spectrum trades, where new spectrum users purchase licences from incumbents.[5] This approach can be limited by a range of barriers such as the ability to trade, transactions costs, costly delay, regulatory requirements, coordination failure between linked bilateral transactions, operators' strategic motivations, and bargaining problems. For instance, firms may have asymmetric information about their

Figure 6.2. Cost and revenue for different band clearance amounts in the USA's 2016–17 incentive auction

Auction stage	TV spectrum to be cleared (MHz)	Mobile spectrum after repacking (MHz)	Cost of clearance ($ billion)	Revenue ($ billion)
1	126	100	86	23
2	114	90	55	22
3	108	80	40	20
4	84	70	10	20

Source: Author from Table 1 in Kwerel et al. (2017).[9]

respective values for the spectrum, which can lead incumbents to hold out against selling in order to increase prices of the trades, or they may seek to acquire or preserve market power through superior spectrum holdings.[6]

Greater coordination can be achieved by two-sided, double, or 'incentive' auctions. A leading example occurred in the USA in 2016–17 where the regulator acted as a clearinghouse, bringing together incumbents (TV broadcasters) to sell their spectrum rights in a 'reverse' auction, and mobile operators to buy the spectrum in a 'forward' auction.[7] The regulator also undertook critical 'repacking', changing the band plan to make it more suitable for the mobile technologies of the new spectrum uses. The four different stages in the incentive auction which decided the amount of spectrum to be cleared are shown in Figure 6.2. As the first two columns show, the complications of repacking meant that more TV spectrum had to be cleared in order to offer a smaller amount of mobile spectrum. The first row shows that the cost of $86 billion to clear the largest amount of TV spectrum (126 MHz), as revealed in the first stage of the auction, would have substantially exceeded revenue from mobile operators of only $23 billion for the corresponding amount of mobile spectrum (100 MHz). So this amount of clearance was rejected, and in the next stage the candidate clearance amount was reduced. Clearance cost still exceeded revenue for the spectrum amounts in the second and third stages. The auction concluded in stage 4 when the clearance amount was reduced to 84 MHz, and 70 MHz was awarded to mobile operators, avoiding a revenue deficit.[8] The USA incentive auction was a major achievement given the engineering, computing, economic design, and practical challenges.

However, the use of such auctions can be limited by legal powers or a suitable economic situation, both of which applied in the UK. The regulator did not have powers to make net payments to auction participants wanting to sell their spectrum licences. In the case of the 700 MHz band, the licences held by the broadcasters were not effective substitutes because they were dispersed across frequencies and locations. All were needed to achieve change of use, so there would have been an absence of competition on the sellers' side of the market. Another possibility, which combines an auction with a trading process, is to award overlay licences that provide rights of use to new licensees that are limited by the need to cause no interference to incumbent users. This can lead to subsequent trades between the overlay licensees and incumbents, one paying the other to give up their rights and perhaps move to alternative, lower-value spectrum, although some desirable transactions could be blocked by the barriers to trading already noted when discussing bilateral spectrum trades.[10]

In the UK and many other countries, regulatory intervention is more typical to achieve change of use of a spectrum band.[11] For the policy ends of a potential change of use, the regulatory decision involves an impact assessment (or social cost-benefit analysis).[12] The analytical framework of impact assessments, comparing costs and benefits, is used for a wide variety of public policy choices. The next subsection begins with a UK case useful for showing how to use impact assessments well, and then draws out the strengths and limitations of the technique more generally. For the means of achieving a change of use, incumbents' existing spectrum licences can be revoked, usually also making alternative spectrum available to them. Decisions to revoke licences are not to be made lightly and require careful justification to mitigate risks of regulatory failure. Once the spectrum band is cleared, it can be awarded to new users via an auction.

Impact assessment for the UK's change of use of the 700 MHz band

The UK regulator (Ofcom) undertook an impact assessment in 2014 of a change of use to clear television broadcasters and other existing users out of their currently occupied 700 MHz band in order to make it available for mobile broadband. A summary of the analysis, used as supporting evidence for the change-of-use decision, is in Figure 6.3. The benefits of change of use to mobile services are on the left-hand side and the costs of moving incumbent broadcasters out of the band are on the right. The upper part shows the effects that were quantified, with unquantified or qualitatively assessed effects in the lower part. The costs that Ofcom was able to quantify were substantial at more than £550 million, but they were comfortably exceeded by the quantified benefits of at least £900 million. In addition, this estimate of substantial net quantified benefits was reinforced by the unquantified benefits, which the regulator considered were larger and more important than the unquantified costs.

The analysis illustrates a number of broader points about the strengths and limitations of an impact assessment.[13] At a high level, the approach brings valuable rigour to the assessment (drawing on underpinnings in welfare economics). The analytical tool is also flexible covering a wide range of techniques, both to quantify impacts and to assess effects more qualitatively. A structured analysis provides a useful discipline to be clear about the *objective* of the policy, in this case optimising the value to consumers from the use of scarce spectrum. The policy proposal is compared to a specified *alternative*, which could be the status quo position, as here. This can help focus attention on effects that are *causally* related to the policy proposal, i.e. on the differences with and without the proposal, which is conceptually different from a comparison of before and after, even if that perspective can sometimes provide useful evidence. Here the regulator was contemplating a single change. However, in another case involving a package of policy proposals, a relevant question would be whether each element of the package was *incrementally* justified, not just the package overall. Another strength of analytical rigour is systematic identification of relevant effects, missing or double-counting none. For example, the regulator included nine distinct categories on the cost side as shown in Figure 6.3 (quantifying eight, including larger and smaller impacts, and assessing the other qualitatively). The regulator paid significant attention to checking that the modelling of benefits to mobile operators avoided double-counting between the two categories of quantified benefit.

One limitation is the risk of obscuring the required policy judgement, since the overarching purpose of the analysis should be to assist informed, *structured judgement*. Identifying key trade-offs and assumptions assists policy judgement, such as by conducting sensitivity analysis (showing how estimated benefits or costs vary with different assumptions) or break-even analysis (showing the necessary scale of benefits to cover costs). Clarifying who gets what, i.e. the distribution of costs or benefits to winners and losers from the proposed policy, also informs the overall judgement. In the example of change of use of the 700 MHz band, the quantification of effects highlighted the balance between the

Figure 6.3. Estimated costs and benefits of change of use of the 700 MHz band to mobile services (net present value in 2014)

<table>
<tr><th></th><th colspan="2">Benefits of change</th><th colspan="2">Costs of change</th></tr>
<tr><td rowspan="9">Quantified</td><td rowspan="2">Improvements in mobile performance</td><td rowspan="2">£390m–480m</td><td>DTT infrastructure costs</td><td>£420m–470m</td></tr>
<tr><td>Consumer information costs</td><td>£25m</td></tr>
<tr><td rowspan="2">Network cost savings</td><td rowspan="2">£480m–770m</td><td>Consumer aerial replacement</td><td>£3m–6m</td></tr>
<tr><td>Re-tuning TVs</td><td>£7m–10m</td></tr>
<tr><td colspan="2" rowspan="4">Reduction in consumer prices: a significant proportion of the network cost savings passed on</td><td>Co-existence costs</td><td>£0–20m</td></tr>
<tr><td>PMSE equipment replacement</td><td>£13m–21m</td></tr>
<tr><td>DTT opportunity cost</td><td>£80m–100m</td></tr>
<tr><td>PMSE upskilling costs</td><td>£10m–13m</td></tr>
<tr><td colspan="2">Total: £900m–1.3bn</td><td colspan="2">Total: £550m–660m</td></tr>
<tr><td rowspan="2">Unquantified</td><td colspan="2">Improved coverage, potential deployment of new services, and increased capacity for public protection and disaster relief</td><td colspan="2">White space devices opportunity cost</td></tr>
<tr><td colspan="2">Effect of unquantified benefits:
Potential for significant upside</td><td colspan="2">Effect of unquantified costs:
Not material to total costs</td></tr>
</table>

Source: Author from Ofcom (2014c).
Notes: DTT: Digital Terrestrial Television.
PMSE: Programme Making and Special Events (wireless cameras and microphones).
So-called 'white space devices' utilise otherwise unused pockets of spectrum in specific locations and frequencies between terrestrial broadcast transmissions.

largest costs and benefits. The infrastructure costs of moving digital terrestrial television broadcasting out of the band to use alternative spectrum were estimated at £420–470 million. The government provided funding to compensate broadcasters for these costs. Mobile operators would benefit from quality improvements and cost savings, and would pass on a significant proportion to consumers through competitive activity.

All relevant costs and benefits should be considered before drawing a conclusion. A potential risk of impact assessment is a preoccupation with economic factors leading to a failure to capture other legitimate points of view. In this example the regulator made efforts to be inclusive about the types of cost or benefit that could be significant but were less amenable to reliable quantification, such as the potential deployment of unknown new services. Sources of broader social value can be relevant in other cases (as Figure 3.1 showed). Figure 6.3 includes quantified and unquantified effects, both within the same *integrated* analysis. It is not uncommon to more readily quantify one side of the equation, in this case the costs. Without a proper consideration of unquantified effects, there is a clear risk of biased conclusions. Just as there is a range of established techniques to quantify effects, so different approaches can also contribute to the qualitative assessment of unquantified effects.[14] One simple example is back-of-the-envelope calculations that do not purport to be robust but can still be useful for decision-making by indicating the order of magnitude of the effects, such as whether they are likely to be large or small.[15]

A further feature of an impact assessment is that it is *forward-looking* and so inevitably involves a degree of uncertainty. For the 700 MHz band there was a long gap between the change-of-use policy decision in 2014 and implementation of the required band clearance, which the regulator only completed in 2020. A general lesson is that it is possible to anticipate long time lags, implying the need for forward planning of band clearance well in advance of implementing a change of use. The impact assessment can capture uncertainty in different ways, such as giving ranges for the estimates. For 700 MHz the ranges were noticeably wider for benefits than for costs, reflecting differential degrees of certainty. Ofcom's 2014 estimate of quantified benefits was £0.9–1.3 billion, and the 700 MHz band sold in the 2021 auction for £0.8 billion (which was broadly consistent, because benefits were expected to be larger than auction revenue).[16] The actual costs at £0.4 billion turned out to be smaller than the estimates.[17]

Ofcom's impact assessment for the 700 MHz band assisted the decision-making process. Some parts of the analysis in the draft version published for consultation with affected stakeholders were more technical and complicated, but the regulator tried to engage in the debate transparently and constructively. The overall case for change of use from broadcasting to mobile was plausible, but because the costs of doing so were substantial, it merited careful analysis. Subsequent events and hindsight suggest that the 2014 impact assessment was reasonable, bringing out clearly the trade-offs involved.

Use or misuse of impact assessments

Impact assessment used well can be a powerful and informative analytical approach. It can improve the quality of evidence for elements of cost or benefit that are more factual. For the elements that inevitably involve judgement, it can organise issues and highlight key trade-offs. Yet it is not always used in this way for public policy decisions. *Underuse* and overuse are ways to describe two types of misuse of impact assessments. Underuse occurs where the impact assessment plays too small a role in the policy judgement, ignoring inconvenient evidence or losing potentially valuable insights. For example, it is not possible to quantify everything reliably, but it is important not to make the perfect the enemy of the good, discarding relevant analysis just because the economic assessment appears to be incomplete or imprecise. Back-of-the-envelope calculations can be useful, and there are a wide range of techniques to provide evidence to add to the debate and avoid unassisted judgement.

By contrast, an *overuse* of impact assessment occurs if we lose the forest for the trees, in which case detail, hubris, or controversy can obscure the overarching purpose of assisting structured judgement. Overuse can arise for a range of reasons. Presenting analysis with spurious precision, or giving quantified estimates that rely on assumptions and a specific methodology as being 'correct' can hide the role that judgement plays in the analysis. Overly complex analysis can also obscure policy judgement, burying key choices in detailed assumptions. Or abstruse methodological issues can exclude the vast majority of the public or affected interests from engaging in the discourse. In addition, overuse of a narrow economic perspective can crowd out legitimate viewpoints relevant to public value that do not fit easily into the orthodox economic framework. For example, a dogmatic view that the assessment should only take quantified impacts into account can lead it to ignore important effects on public value that are hard to quantify or not give them due weight in the overall conclusion.[18] Those dubbed 'econocrats'[19] adopt this exclusionary approach.

Many of these problems unfortunately follow a dynamic that seems to be inherent to the process. Public organisations with the responsibility for making or advising on the policy decision may face a procedural requirement that they undertake impact assessments, sometimes subject to external review. This is sometimes justified as ‘deck stacking’ to open up information and enable participation by interest groups.[20] At its best, it can encourage more evidence-based decisions. But it often also invites a tick-box approach, stimulating only the retrofitting of a decision that the public organisation has already reached by other means, creative ways to neuter or bypass the requirement, or – as with overuse – distracting debate from the meaningful questions for policy judgement. Therefore, the procedural requirement can suffer from endemic regulatory failures of ineffectiveness and unintended consequences, including at its worst degrading the decision-making process while also consuming time and resources. Ironically, this might even raise questions about whether a requirement to undertake impact assessment would itself pass a cost-benefit test.

Private companies affected by potential policy changes can also engage in gaming that goes beyond legitimately representing their interests and instead involves rent-seeking. Common tactics include submitting selective or misleading information, ‘burying’ the public organisation under a deluge of documents that are difficult or time-consuming to assess, and arguing for ever greater detail in the impact assessment that does more to add complexity than shed light. Companies may use these and various other tactics to delay a conclusion they perceive as likely to be unfavourable.

As ever, the regulator needs to strike a balance. Criticisms of an official analysis and additional evidence can be valuable correctives to a sloppy or partial assessment. But unrealistic demands are often unhelpful and can be counterproductive to good decision-making. Above all, policymakers should recognise that making a structured policy judgement is central, and the role of the impact assessment in this process is more modest than reaching a (usually spurious) definitive conclusion. What matters is steering a course between *confidence* that well-judged impact assessments add value (as a counter to underuse) and a measure of *humility* about how far the analysis can take the debate (as a corrective to overuse). Unfortunately, many barriers and incentives can get in the way of achieving this vision. Chapter 10 shows how auctions can contribute – without substituting for policy judgement, bid incentives can, for instance, induce operators to provide better-quality information for parts of the impact assessment relating to decisions on competition measures and coverage obligations.

6.2 Licensing as market design decisions

The items on offer in spectrum auctions are licences that provide legal entitlements to make radio transmissions in specified frequencies. There are many different licensing approaches to make spectrum available. Before coming to the options, it is useful to establish the basis or high-level framework that underpins the choice, which is the balance between market imperfections and regulatory failure.

Rationale for licensing and the Coase theorem

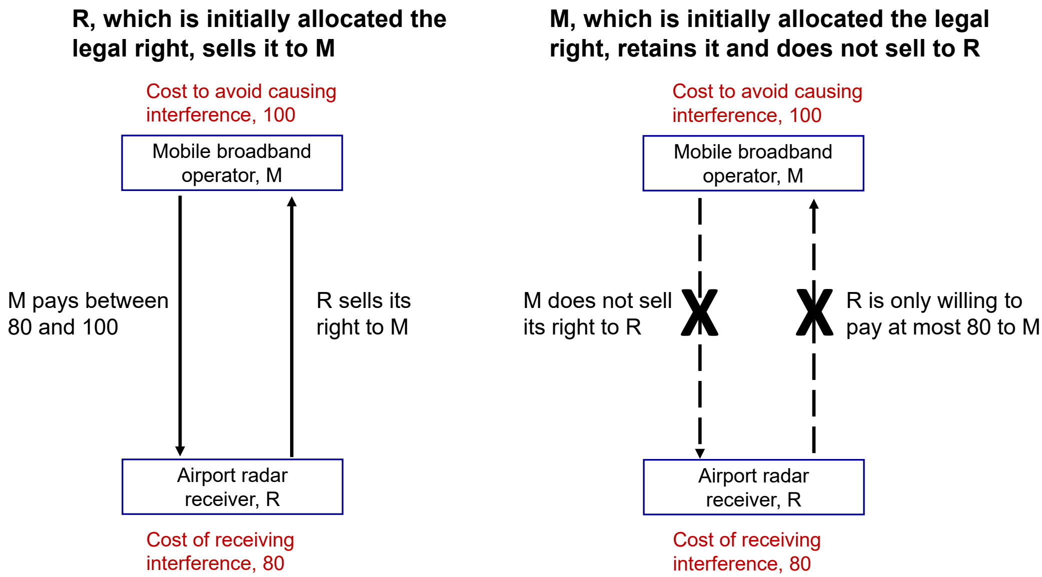
Spectrum is a natural resource, classified in economic terms as a common pool resource. Without regulation, it is *rival* in use, since the radio transmissions of one user generally cause harmful interference for other users who are nearby in location or frequency. Therefore, apart from frequencies that are technologically difficult to use or in remote geographies, much spectrum is scarce, meaning that not all spectrum demands can be satisfied. Unregulated, spectrum is also *non-excludable*, because it is available for all to use.[21] Examples of other common pool resources are irrigation systems, and renewable natural resources such as fishery stocks or forests. The market failure to which such resources are prone is too much use, such as overfishing that depletes fishery stocks. This is sometimes called the 'tragedy of the commons', although excessive resource depletion is a market failure even without exhausting the resource.[22] For spectrum, too much use is reflected in radio transmissions interfering with each other. This is an example of a market failure based on a negative externality — a spectrum user does not have an incentive to take into account the costs imposed on a neighbouring user.

Underpinning the externality problem are more fundamental market failures relating to property rights and transactions costs. The Coase theorem captures the underlying thinking, based on two papers by Ronald Coase. The first paper in 1959 was about management of the radio spectrum and proposed the use of spectrum auctions, while the second paper in 1960 developed the thinking further about market responses to externalities (and it has been rated as the most cited law review article of all time).[23] There are several ways to state the theorem. But the most useful for our purposes is this: if property rights are defined and tradeable, and there are no transactions costs, the market can internalise externalities. In such an (ideal) world, who initially owns property rights has no effect on ultimately achieving the efficient economic allocation of the resources.[24] In essence, although legal entitlements create the initial allocation, the market can determine the final allocation through trading. Parties trade if it is profitable, and the opportunity for a trade provides the incentive for one party, M, to take account of the external effect of its actions on another party, R, with which it can trade. This internalises the negative externality, alleviating the market failure. The initial allocation does not change the gains from trade (under the idealised assumptions), because there is a reciprocal effect between the trading parties. M's behaviour imposes an external cost on R, but changing behaviour to avoid it would impose a cost on M – the gains from trade depend on the difference between these costs. However, the assumption in the Coase theorem of no transactions costs is relevant because it is a barrier to trading. Transactions costs mean that the gain from trade has to be large enough to more than offset them, or the status quo will endure. Thus some trades to achieve the efficient allocation might not occur, and the initial legal entitlements could affect the final allocation.

A simplified spectrum example of the Coase theorem is shown in Figure 6.4, using illustrative figures. The same considerations affecting the profitability of the trade are in play, regardless of which party (M or R) has the initial legal entitlement. Here let M be a mobile broadband operator who causes interference to an airport radar receiver operated by R. Whether the airport radar initially has a legal right not to receive interference, or the mobile operator has a right to transmit interference, the same ultimate outcome is achieved (in the absence of transactions costs).

The specific outcome depends on the relative costs regarding interference. In the example in Figure 6.4, the mobile operator ends up with a right to transmit. It benefits by more, because its cost to *avoid causing* interference (100) is larger than the airport radar's cost of *receiving* interference (80). In the first outcome, detailed on the left-hand side of Figure 6.4, it makes sense for the mobile operator to buy the right to impose interference on the airport. The mobile operator is willing to pay a price up to the cost of 100 to avoid causing the interference (such as its loss of profit from a reduced coverage footprint). It can therefore offer a price for the trade that the airport is happy to accept, because it can cover the airport's cost of 80 from receiving interference to its radar (such as fitting a filter to avoid interference disrupting the radar). In the second case, on the right-hand side, the mobile operator initially has the right to transmit and retains it, because its cost to avoid generating interference on the airport radar is larger than the price the airport is willing to offer to stop it.

Figure 6.4. Coase theorem numerical example with reciprocal incentives to trade (and no transactions costs)



Source: Author.

To put the Coase theorem into effect, property or usage rights need to be defined in licences (or other types of authorisation), which are tradeable. The ability to trade is not enough to ensure efficient allocation because there also needs to be no transactions costs, or other barriers to trade such as market power, strategic motivations, bargaining problems, or coordination failures between linked trades of multiple parties. Thus the assumptions required for the Coase theorem to work are not necessarily realistic. However, it provides a useful conceptual benchmark. One insight is that there can be market solutions to externalities if the conditions are suitable (that is, tolerably close to the Coase theorem assumptions), such as for pollution permits which can usually be traded at low transaction costs.

Another feature of the Coase theorem is that it is about improving economic efficiency, not revenue-raising or distributional effects that are also included in the wider concept of public value. For example, gifting a polluter too many permits could allow it to continue polluting, sell excess permits, and make a profit. Under the Coase theorem conditions, this would enhance economic efficiency of the allocation of permits. But a polluter profiting in this way may conflict with other public values. Another way to achieve the efficiency of the allocation would be if the polluter had to pay for the pollution permits, for example if they were sold by auction.[25] In that way, the public purse would receive more of the revenue than the polluter. Some people go further, taking the view that monetary transactions for pollution permits or the idea of a right to pollute are ethically repugnant.[26] Instead of tradeable pollution permits, there could be more of a command-and-control approach where a regulator sets quantity limits on each company's amount of pollution. Or there could be a tax on pollution, which is another way in principle to internalise the externality and provide the polluter with an incentive to take into account the external cost it causes. Both of these alternatives to trading have high informational requirements on the regulator or tax authority to set appropriate quantity limits or tax rates in order to avoid significant regulatory failure.

With the licensing approach, if barriers to trade are significant, then the Coase theorem implies that trading markets are not enough to achieve an efficient allocation. In those circumstances, we need to think carefully about how to achieve the primary allocation of legal entitlements. This is the case for mobile spectrum, because trading markets are generally thin and illiquid, and there are transactions costs and strategic motivations.[27] A spectrum auction is a market method of primary allocation. Non-market alternative methods include lotteries or comparative selection (beauty contests) – see Section 2.2.

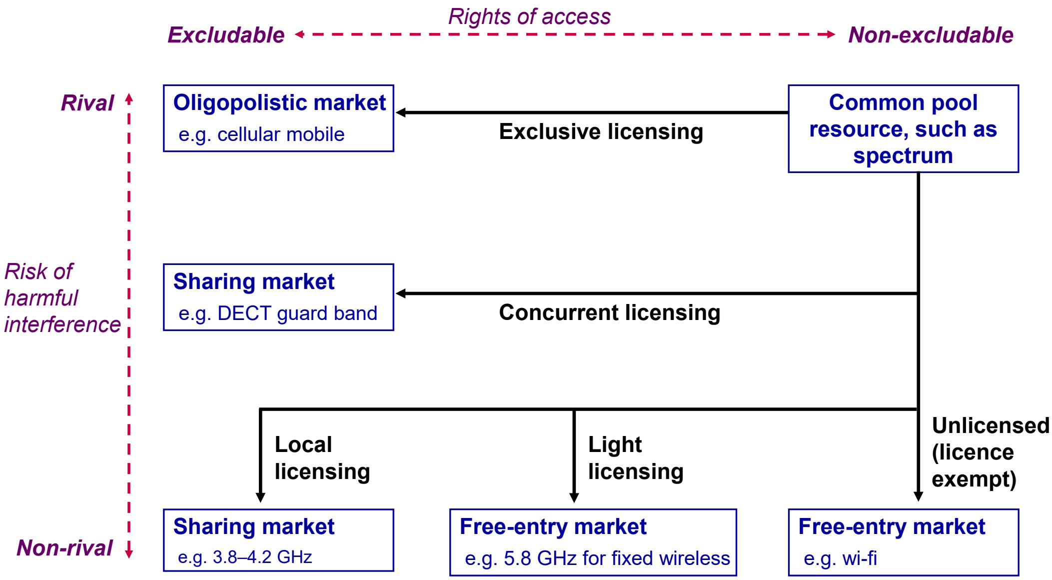
Spectrum licence choices implying different types of market

One response to the market failure from harmful spectrum interference is command-and-control regulation. This has usually taken the form of a requirement to hold a licence to make radio transmissions, plus setting licence conditions that limit what the licensee can do, such as the technology and/or services for which it can use the spectrum. The technical specification of these rights is crucially important to the outcome and efficient spectrum use. Licences that are more technology-neutral allow the licensee greater freedom to vary services (such as fixed wireless as well as mobile) and enhance trading opportunities.[28]

Command-and-control solutions can be suitable, but they may encounter regulatory failure, where the regulated terms of access are too onerous and restrictive. The inefficiency takes the form of idle spectrum that is unused, or underused because it is not in the hands of licensees who would generate the greatest value from it. Command-and-control regulation could therefore fail to achieve the objective of maximising social and public value. One reason is difficulties in picking the right winners. Another problem is the pace of the regulatory process failing to keep up with the speed of technological and commercial developments (for instance, the machinery of international negotiations at the World Radio Conference grinds slowly). There can also be unintended consequences, such as complexity that excludes affected stakeholders from public discourse. Or there can be a regulatory bias towards incumbents because they have a voice 'in the room' and clearer established interests to protect than new wireless entrants without an existing spectrum-based business.

In exploring how market mechanisms can assist efficient outcomes, there is a distinction between the type of spectrum (input) market and the consequences for the downstream (output) market. For the spectrum market, Figure 6.5 shows the implications of different types of licensing, from exclusive licences to licence exemption, and various models in between such as spectrum sharing. Because a decision on the licensing model can substantially change the nature of the spectrum market, such as from free entry to oligopolistic, it is possible to view it as a market design choice. For instance, many countries deploy a range of licensing approaches for different purposes, and the UK's regulatory regime makes use of all of these licensing models.[29] The vertical axis shows the degree to which spectrum use is rival or non-rival. Rivalry means that there is competition to use specific spectrum (such as a frequency in a specified area) because users can impose harmful interference on each other. The horizontal axis shows the extent to which the rights of access to spectrum are excludable or non-excludable. For example, an exclusive licence provides rights allowing the licensee to exclude use of the spectrum by others. Before making any regulation or licensing choices, spectrum is rival and non-excludable – the defining characteristics of a common pool resource.

Figure 6.5. Licensing models and types of spectrum market



Source: Author.
Note: The name 'DECT guard band' derives from this band being between the frequencies used by cordless telephones (Digital Enhanced Cordless Telecommunications) and mobile networks, originally to avoid harmful interference between them.

In the top left of Figure 6.5, one choice for the regulator is to issue a limited number of exclusive licences, changing the economic nature of spectrum by making rights of use excludable.[30] It remains rival, because there are still risks of harmful interference. Denying the availability of that spectrum to others is reflected in an opportunity cost, the loss of value from the best alternative user of the spectrum. Auctions and secondary trading of the limited number of exclusive licences can promote efficient allocation, taking account of insights from the Coase theorem. Exclusive licensing is the approach generally used for mobile spectrum, and it contributes to a limited number of downstream market players in an oligopolistic market structure.

A very different approach in the bottom right of Figure 6.5 is licence exemption, with no requirement on a spectrum user to hold a licence.[31] The non-excludable characteristic of spectrum is retained, and the spectrum market involves free entry. Rules can address the interference problems that make spectrum a rival resource by removing, or at least substantially reducing, the risks of interference.[32] Wi-fi, which is ubiquitous in homes, offices, and public spaces, uses licence-exempt spectrum bands. The rules require the wi-fi operator to transmit radio signals at sufficiently low power to avoid harmful interference with others.

Between these poles, Figure 6.5 also shows three examples of other licensing models for spectrum sharing.[33] In the middle of the bottom row is a variation on licence exemption, light licensing, where a licence is required, but free entry is maintained because there is no limit on the number of licences that can be issued. This alternative could be useful where a current or future risk of interference between spectrum users is low but cannot be ruled out. With licence exemption, it would be hard to manage the interference if it occurred, since users would be unknown, whereas with light licensing there is greater scope for solutions as the regulator knows the identity of the licensees.

With concurrent licences all holders have an equal right to use the same spectrum. There is a limited number of licensees who must find a way to coordinate so as to mitigate interference risk, such as adopting protocols agreed between them or set by the regulator. An example in the UK was the so-called DECT guard band which is so close to one of the main mobile spectrum bands that mobile users' normal handsets can also tune into these frequencies. In 2006, an auction awarded concurrent licences for the band for local area networks (such as those covering an office, warehouse, or campus). This licensing model is positioned in Figure 6.5 on the left below exclusive licences, because there remains some (but much less) risk of rival use. Later on, the regulator changed the licensing approach for the DECT guard band spectrum to licence exemption, due to an updated understanding that the externality risks from interference were sufficiently low, so allowing free entry.

Local licences provide another example of spectrum sharing, offering a reduced risk of interference because they relate to specific, small geographic areas (e.g. a 50-metre radius) and may impose limits on the power of transmissions.[34] The regulator may issue only one licence per localised area, but many local licensees can coexist in nearby locations. In this sense there is shared use of the spectrum, and it is characterised in Figure 6.5 as being close to non-rival (while being excludable because of the need for a licence).[35]

Across a nation or a region there does not have to be an all-or-nothing choice of just one licensing model for all frequency bands and areas, because the types of licence and spectrum market have different strengths and limitations. For example, exclusive licensing is more suited to a small number of networks with large sunk-cost investments like mobile networks, but it involves high barriers to entry. Licensing models that support sharing can restrict the spectrum available to any user but can also allow the resource to be used more efficiently. In licence-exempt spectrum the requirement for low power transmissions places some limits on the type of networks and their coverage footprint, but there is a low cost of entry which allows experimentation and entry by a much wider set of providers – for instance, the enormous contribution of wi-fi is not in doubt. The range of licensing approaches can support innovation of different types. Because spectrum is an input, various bands with different licensing models can be used to offer distinct or similar downstream services to consumers. So the real policy question is not an either/or choice, but judging the appropriate balance between types of licensing model across frequency bands or areas, and their associated different types of spectrum market.[36]

The time dimension: licence duration and award date

Timeliness is one of the features of a successful market. The duration of the licence is an important dimension that can affect the efficiency of the spectrum allocation, and the licensees' security of tenure can change their incentives for investment and innovation. The UK regime for mobile spectrum licences has been relatively unusual in issuing licences of indefinite duration. Annual licence fees are payable after an initial term (such as 20 years), based on the regulator's estimate of the opportunity cost.[37] Such fees can stimulate trades so as to reallocate licences from incumbents to higher-value users. By contrast, most other countries issue fixed-term licences, allowing either renewals or periodic auctions that can adjust the spectrum allocation. The fixed duration can run a risk of deterring investment, especially as the end of the licence term approaches. However, if there are sufficiently strong expectations of renewal, fixed-term licences can have investment incentives more like indefinite licences. Either regime can work, but some academics have suggested a novel approach to have the best of both worlds, namely 'foothold auctions' of partial-ownership ('depreciating') licences. These licences can be regularly re-auctioned, promoting efficient allocation. Incumbent licensees are compensated if they lose the auction, maintaining their investment incentives.[38]

A different timing question is when to award the licences that are being offered. For example, in theory the UK regulator could have held its 700 MHz auction soon after making the change-of-use decision in 2014. However, there would have been a lot of uncertainty. The initial decision only started the clearance process, but it took many years (until 2020) to modify the broadcasting infrastructure so that mobile services could use the band. Holding the auction too far in advance of network deployment means that mobile operators could find it hard to forecast their future costs and consumer demand to value the spectrum. Also, the pace of technology developments is not always predictable, so that the importance of different frequency bands could vary and be subject to surprises.

The balance for the regulator to strike is to hold the award at the most propitious time, not too soon but also not too late. Delaying deployment defers the time when consumers gain the benefit of the new mobile spectrum. The long timelines involved in the policy development process for auctions and the many sources of potential delay make the problem of being too late more likely in practice. For example, merger activity and litigation by operators deferred the UK's 2018 auction, and the Covid-19 pandemic delayed the 2021 auction. It can help for the regulator to take a strategic approach, setting the future of any individual band transparently in the context of a longer-term pipeline or roadmap of future spectrum releases. This approach assists planning on the supply side by the regulator and on the demand side by operators.

Conclusion on licensing choices

The aim of the discussion in this section has been to show the application of a market design perspective to the choice of spectrum licensing model, because it can substantially change the nature of the spectrum market. The underpinning of this choice is a response to interference and spectrum scarcity that strikes a balance between market failure and regulatory failure. The type of licence also affects the choice between market mechanisms and non-market approaches to spectrum allocation – for instance, spectrum auctions only make sense if spectrum should be licensed, and not licence-exempt. The economic efficiency advantages of auctions are generally important for exclusive licences. There are exceptions, however, and non-market allocation methods may be more suitable for other types of licence. For instance, light licences are unlimited, and local licences can be better suited to first-come, first-served allocation. Choosing to pursue exclusive licensing and to auction mobile spectrum has far-reaching implications. The resulting small number of operators that bid in auctions is one of the fundamental complications in spectrum auction design, due to the scope for strategic bidding. The need for a licence contributes to high barriers to entry, which make a careful assessment of competition measures important for auctions of mobile spectrum.

Notes

1 Hazlett and Muňoz (2009a).

2 Lewis (2018), and Hazlett and Muňoz (2009b).

3 Satellite broadcasting also uses spectrum, but often at much higher frequencies (such as 10 GHz or above) which usually have lower opportunity costs.

4 Ofcom (2020c).

[5] Examples include the Qualcomm trade of 1452–1492 MHz in the UK (see Figure 11.8), or Nextel in the late 1980s in the USA as reported in Hazlett and Leo (2011).

[6] Milgrom (2004, section 3.3.5), and Cramton, Kwerel, and Williams (1998). For analysis of how the USA's incentive auction reduced incentives to hold out, see Kwerel et al. (2017).

[7] Leyton-Brown, Milgrom, and Segal (2017). The definition of incumbents' spectrum rights played an important role (e.g. maintaining their coverage area, but not a specific channel) – see Kwerel et al. (2017, section 2.3).

[8] For an explanation of the rule deciding when the incentive auction would end, see FCC 'How It Works: The Incentive Auction Explained, Final Stage Rule', https://perma.cc/M9U6-TP2B.

[9] See also Paul Milgrom's 2019–20 Marshall lecture: https://www.youtube.com/watch?v=a0FhGXxY3mE.

[10] For examples of overlay licences in the USA, see Cramton, Kwerel, and Williams (1998). For a comparison between an overlay approach and the incentive auction, see Kwerel et al. (2017, section 2.3).

[11] For an economic analysis of alternative forms of regulatory intervention in the context of the USA, see Rosston and Skrzypacz (2021).

[12] See Weimer (2008) and Hansson (2010) for an overview of methodological and philosophical issues in cost-benefit analysis.

[13] Rose-Ackerman (2011).

[14] HM Treasury (2020), and Department for Communities and Local Government (2009).

[15] Carrigan and Shapiro (2017).

[16] The estimated benefits were cost savings to those using the spectrum (the winning bidders) and quality improvements to consumers from better coverage. The auction prices and revenue reflect such sources of value to the highest losing bidder, which are smaller than to the winning bidders, and bidders' values also exclude consumer surplus gains.

[17] Ofcom (2021a, p.21).

[18] '… care should be taken to assure that quantitative factors do not dominate important qualitative factors in decision-making', Arrow et al. (1996, p.222).

[19] Self (1975).

[20] McCubbins, Noll and Weingast (1987).

[21] Stavins (2011).

[22] Hardin (1968, p.1244). For a critique, see Frischmann, Marciano, and Ramello (2019).

[23] Coase (1959, 1960), and Shapiro and Pearse (2012).

[24] See Medema (2020) for different Coase theorem definitions and controversies.

[25] For an experimental study suggesting that auctions of pollution permits achieve increased efficiency compared to gifting permits in proportion to past emissions ('grandfathering'), see Goeree et al. (2010).

[26] There is a discussion, for example, of value-based objections to pollution permits at minutes 19–23 in Michael Sandel's 2009 Reith lecture on 'Markets and Morals' https://www.bbc.co.uk/programmes/b00kt7sh.

[27] Further limits and assumptions of the Coase theorem are noted by Milgrom (2004, pp.19–21).

[28] Hazlett and Leo (2011).

[29] OECD (2022) and Ofcom (2020f, section 3).

[30] Exclusive licences are referred to for simplicity, although they are more accurately described as individual licences in the UK regime. The regulator can award additional licences for the same spectrum already included in existing individual licences, which would not be possible if the licences were exclusive. A particular example is Ofcom awarding Local Access licences in specific geographic locations in frequencies already in the licence of one of the national mobile operators to local providers of wireless broadband, such as to serve a caravan park – see Ofcom (2019). This is after representations by, and usually with the agreement of, the mobile operator who is not using the spectrum, e.g. in a rural area. Another approach is different access tiers, as for the 3.5 GHz band in the USA with a tier for incumbents, and then tiers for users with priority and secondary access rights (see FCC '3.5 GHz Band Overview', https://perma.cc/EJ5V-JVJG). An approach of secondary use to promote local solutions to rural mobile coverage in Africa is advocated by Steve Song 'Spectrum Auctions Are Killing Competition And Failing Rural Access', 4 April 2019, https://perma.cc/3BDH-NG3S.

[31] Brake (2015).

[32] In general, the rules for a commons may be set by a regulator or collectively by participants through self-regulation — see Ostrom (2008).

[33] For a discussion of different licensing approaches to spectrum sharing, see OECD (2022, pp.40–52).

[34] An example is Shared Access licences – see Ofcom (2019).

[35] Another approach to spectrum sharing that is potentially consistent with a number of different licensing models is dynamic spectrum management that can reallocate spectrum in real time between users – see Wireless Innovation Forum 'Top Ten Most Wanted Innovations, Innovation #1: Dynamic Spectrum Management', https://perma.cc/5USH-DBMS.

[36] For example, even within the same frequency band, Ofcom (2022) proposes to use a mixture of both exclusive and local licences.

[37] Annual licence fees are also paid on administratively allocated mobile spectrum, 900 MHz and 1800 MHz – see Ofcom (2015).

[38] Milgrom, Weyl, and Zhang (2017); and Weyl and Zhang (2022).

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Note: means an open access publication.

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7. Auction design objectives and baseline decisions

Summary

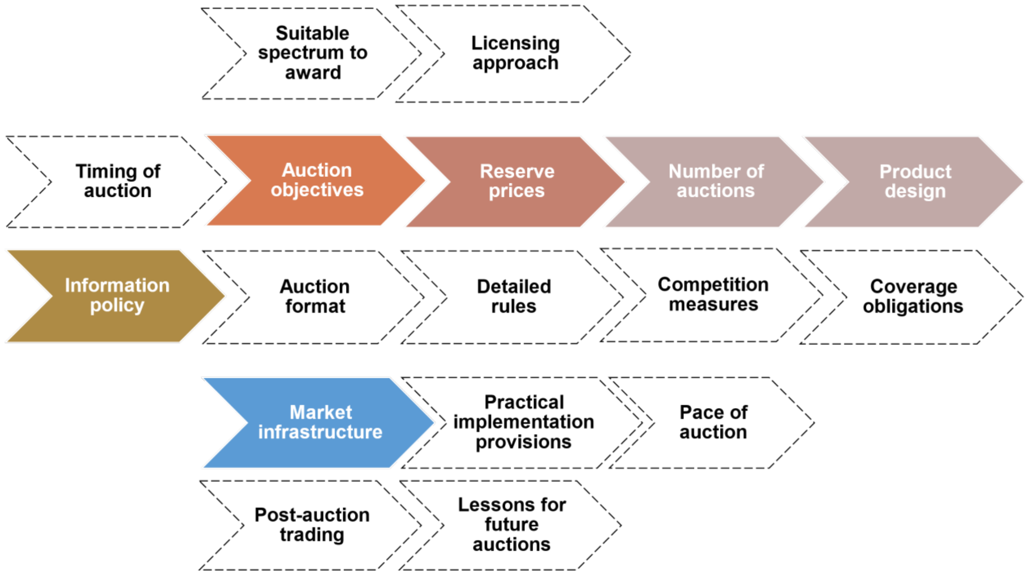
- Auction revenue attracts attention and maximising it can be a legitimate policy objective, but it should be subsidiary to improving economic efficiency because the effects of spectrum auctions on consumer benefits are typically much larger.
- Neither economic efficiency nor revenue-raising is served 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

How to cite this book chapter:

Myers, Geoffrey (2023) *Spectrum Auctions: Designing markets to benefit the public, industry and the economy*, London: LSE Press, pp. 115–136. https://doi.org/10.31389/lsepress.spa.g. License: CC BY-NC-ND 4.0

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).

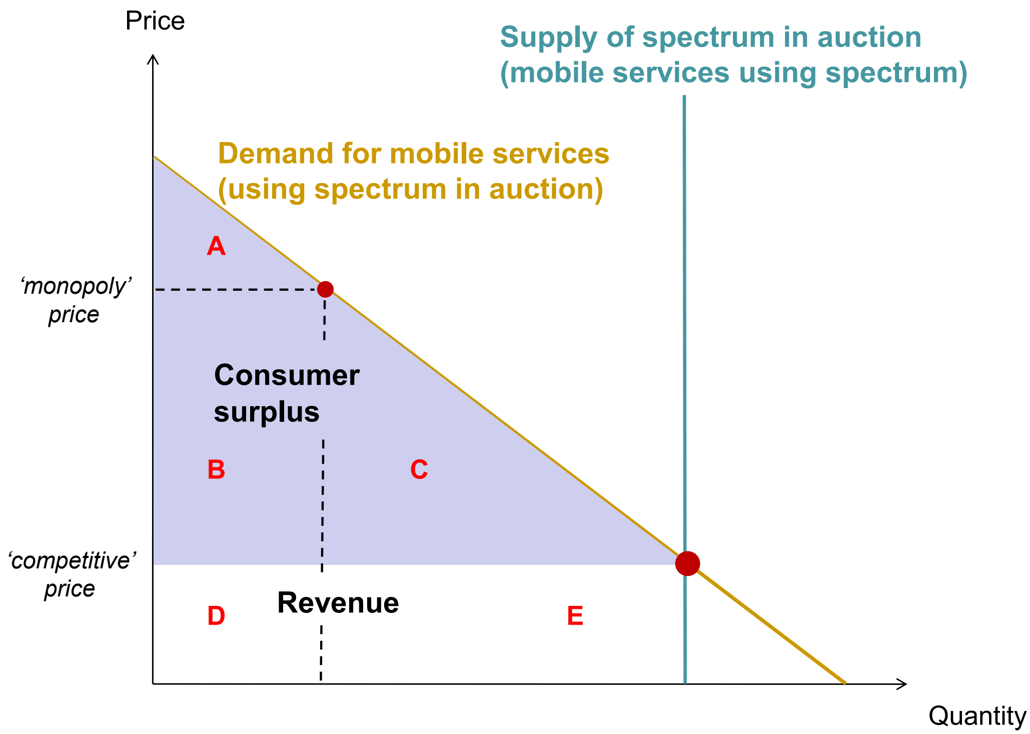
7.2 Objectives: why economic efficiency is more important than revenue

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]

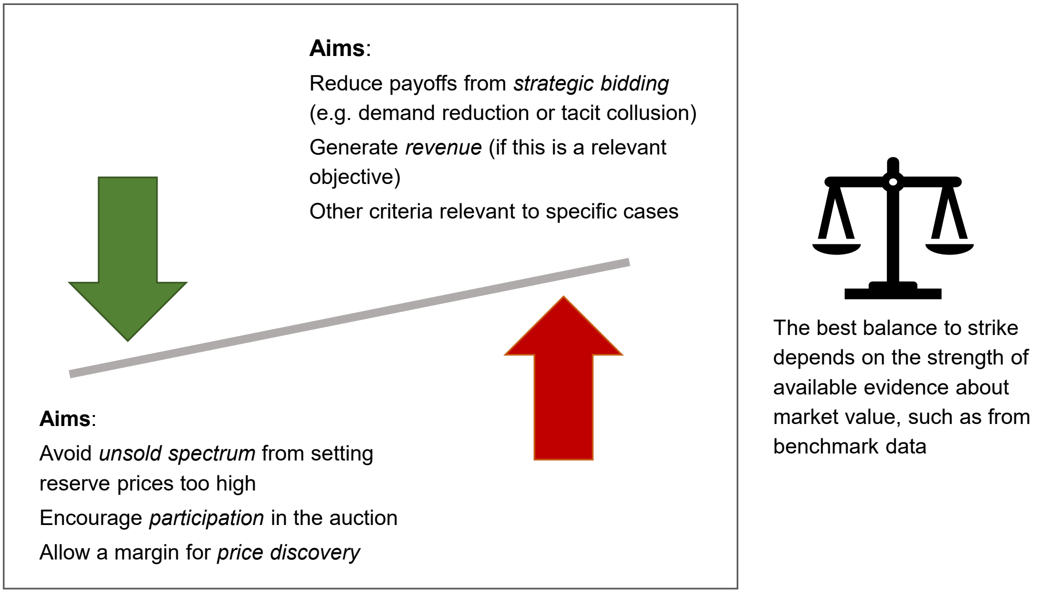
To the extent that the contested effects on investment or consumer prices are present, they represent a reduced risk when the key objective of (auction and output) efficiency is appropriately prioritised over revenue. In economic efficiency terms, there is an asymmetry – if high prices prevent or delay 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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8. Choosing an auction format

Summary

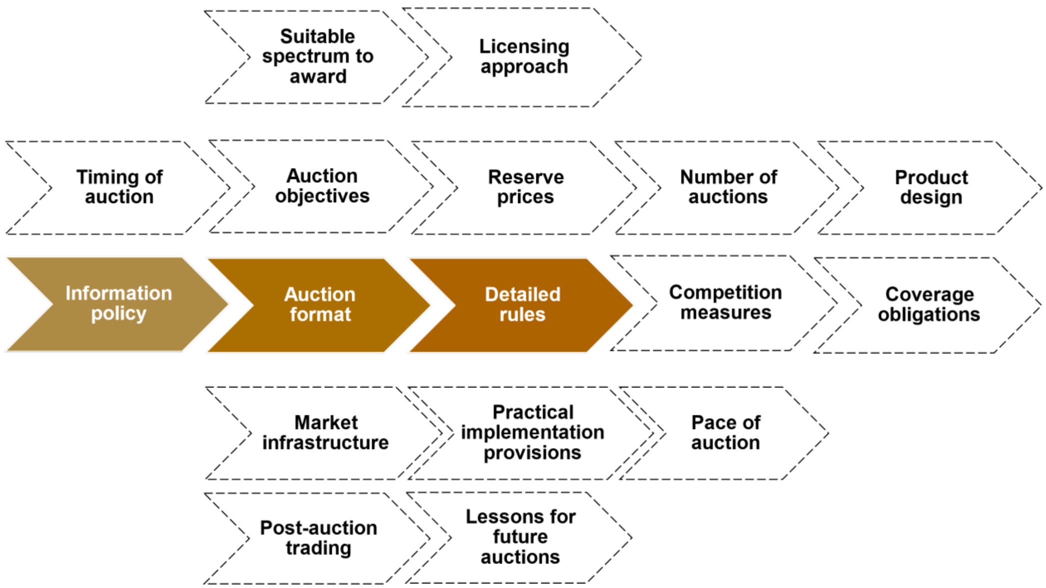
- This chapter explores in detail how the main formats for spectrum auctions operate, looking at: Simultaneous Multiple Round Ascending Auctions (SMRAs) with individual bids and a first-price rule; and Combinatorial Clock Auctions (CCAs) with package bids in an initial stage of multiple rounds, followed 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

How to cite this book chapter:

Myers, Geoffrey (2023) *Spectrum Auctions: Designing markets to benefit the public, industry and the economy*, London: LSE Press, pp. 137–161. https://doi.org/10.31389/lsepress.spa.h.

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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9. Promoting downstream competition

Summary

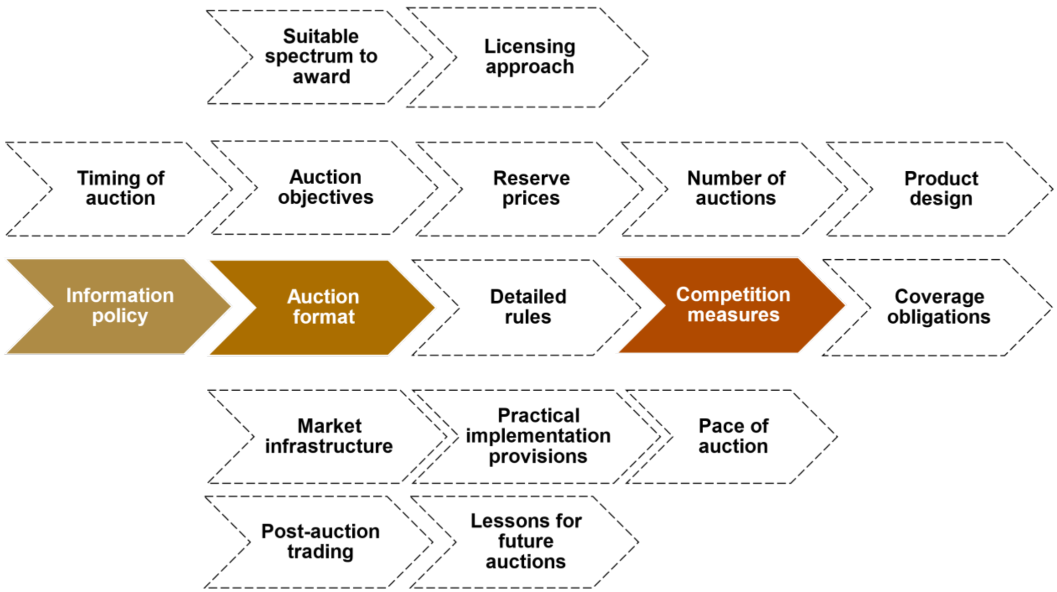
- Major spectrum auctions can strongly affect downstream competition in services provided to the public. So, an assessment of the likely competition effects of auction outcomes is crucial. Three steps are recommended in a structured analytical framework.
- Step 1 identifies the risk of downstream market failure occurring after the auction, which might cause a weakening in competition by affecting the number of operators or reducing the strength of competition between them. Step 2 assesses possible upstream market failure – the risk that the worrying outcomes identified in step 1 occur in the auction. Finally, in step 3 the regulator judges what effective and proportionate competition measures to impose, such as caps to limit spectrum acquisitions or reservations of spectrum for new entrants, paying attention to regulatory failure risks.
- Decisions on competition measures in the UK and an example from Australia highlight the benefits of including all three steps to ensure appropriate measures, while avoiding the excessive intervention that can result from neglecting any aspect of the framework, such as whether operators who need spectrum could acquire it in the auction without any additional regulation (step 2), and the potential downsides of restrictive competition measures (step 3).

The leading auction theorist, Paul Klemperer, has noted: 'The most important issues in auction design are the traditional concerns of competition policy – preventing collusive, predatory, and entry-deterring behavior'.[1] Chapter 8 covered some of these points, including reduced competition in the auction (such as tacitly collusive market division, or predatory price driving). This chapter assesses concerns about strategic investment, namely bidding behaviour in the auction that is designed to deter entry or otherwise weaken competition in the downstream market, adversely affecting consumers and

How to cite this book chapter:

Myers, Geoffrey (2023) *Spectrum Auctions: Designing markets to benefit the public, industry and the economy*, London: LSE Press, pp. 163–183. https://doi.org/10.31389/lsepress.spa.i. License: CC BY-NC-ND 4.0

Figure 9.1. Auction decisions relevant to Chapter 9



Source: Author.

output efficiency. The concerns can be addressed by imposing competition measures in the auction. The auction format and information policy are also relevant as they can facilitate or constrain anti-competitive bidding incentives. These three elements are highlighted in Figure 9.1.

Spectrum is a key input into downstream wireless markets, and what ultimately matters for consumers is how well served they are by competition in those markets in the short and long run through prices, quality, choice, and innovation. At issue here are the effects at two market levels: how outcomes in the *upstream* auction market affect operators' spectrum portfolios, and how those in turn impact on outcomes in *downstream* markets for services sold to consumers. The first relationship is easier to measure in terms of, for example, operators' total spectrum holdings and relative spectrum shares. However, the overall absolute and relative strength of an operator's spectrum portfolio also depends on additional considerations beyond these relevant but fairly crude metrics, such as the portfolio composition (for example between coverage and capacity spectrum), and how it interacts with commercial strategies. The second relationship about the impact on downstream outcomes is harder to establish. Though spectrum is a necessary requirement for new entry by a wireless operator, there is no rigid relationship between concentration in spectrum holdings and downstream market concentration, nor between market concentration and consumer welfare.[2] It is important to keep these nuances in mind when assessing the rationale for any competition measures in the auction.

The first section explains the role of spectrum policy in promoting mobile competition, drawing on the UK's experience. The second section sets out the UK regulator's structured framework to assess competition effects and to decide which competition measures to apply in the auction. The framework is applied, first, to UK auctions, and then in the third section to an example from Australia in 2021.

9.1 Promoting mobile competition through spectrum policy in the UK

The UK regulator Ofcom has developed and applied a structured framework for rigorous, evidence-based analysis. Competition measures are usually contentious with the industry because operators have divergent interests, and in the UK the asymmetries between mobile operators' spectrum portfolios have made them especially controversial. As a result, the regulatory analysis has been intensely examined and tested (including through litigation – see Section 5.4). Nonetheless, the UK has been proactive in applying measures to promote competition, and Figure 9.2 shows how the spectrum caps and reservations affected the auction outcomes (the final column), although in later auctions they acted more as safeguards without being binding constraints. The measures also included innovation in design through the use of spectrum floors in the UK's 2013 auction – flexible spectrum reservation where, instead of being chosen by the regulator before the auction (set-aside), the spectrum ultimately reserved was determined through bids within the auction, so as to mitigate regulatory failure risk (see Section 10.1).

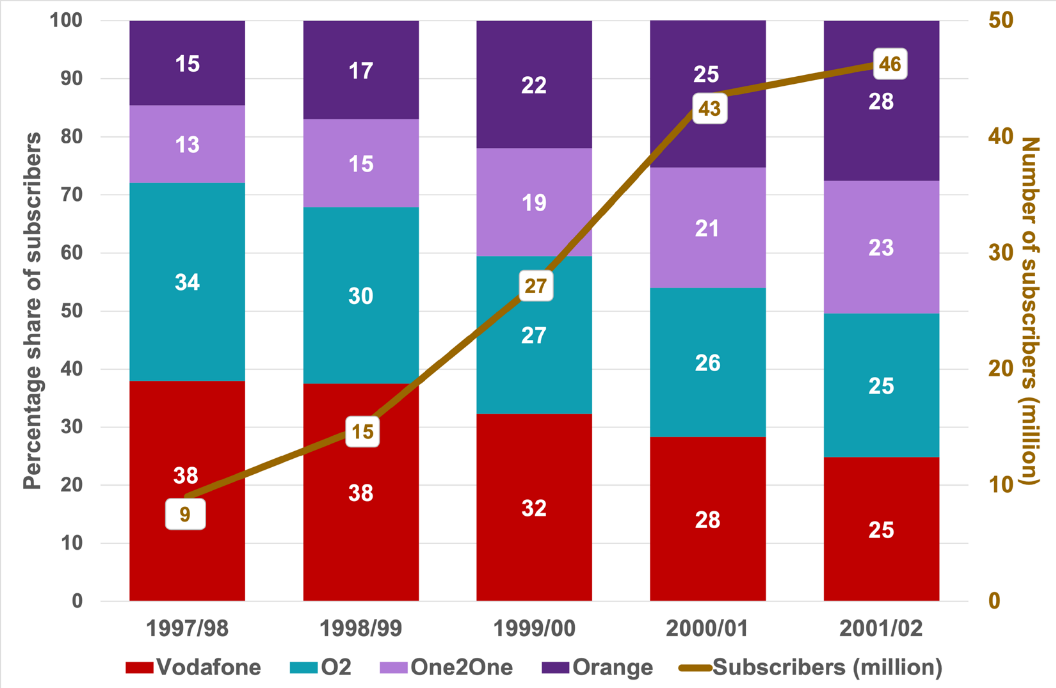
Historically, UK regulators have always recognised the importance of spectrum policy in shaping downstream competition in wireless services. Even before auctions were introduced, spectrum allocation was deployed to improve the competitive structure of the mobile market. The original mobile spectrum (900 MHz band) was administratively allocated in 1985 to two operators: Vodafone, and Cellnet which adopted the brand name O_2 many years later and was taken over by Telefónica. In 1991 when further mobile spectrum became available (1800 MHz), 80 per cent of the band was administratively allocated to new entrants, Orange and One2One, changing the UK from a two-player to a four-player market. This was very successful in promoting competition. The new entrants caught up with incumbents, achieving similar market shares through acquiring customers at a time when the

Figure 9.2. Summary of competition measures in high-stakes auctions in the UK

Auction	Spectrum caps	Reservations	Outcome
2000, 3G auction	Bidders were limited to at most one licence.	One licence was reserved for a new entrant.	One new entrant (changing the downstream market from four to five operators).
2013, 4G auction	Two caps: • Total spectrum • Low frequency spectrum	There was flexible reservation (spectrum floors) for a new entrant or the smallest incumbent (H3G).	Both caps were binding. H3G won the floor in 800 MHz (maintaining four operators in the downstream market).
2018, PSSR auction	Two caps: • Total spectrum • Immediately useable spectrum	None	The total spectrum cap was not a binding constraint. The other cap prevented EE from bidding for the 2.3 GHz band.
2021, 5G auction	One cap on total spectrum.	None	The cap was not a binding constraint.

Source: Author from Ofcom auction documents.
Note: Annex A1 sets out further details of the sizes of caps and reservations in these auctions.

Figure 9.3. Percentage market shares of UK mobile operators, and expansion in the number of mobile subscribers, 1997 to 2002



Source: Author from Oftel (2003).
Note: Total of shares in 2001/02 does not sum to 100 per cent due to rounding.

market was expanding rapidly from one million subscribers in 1992 to more than 40 million a decade later. Figure 9.3 shows the latter part of this period. The combined share of the new operators, Orange and One2One (shown in darker and lighter purple), increased from less than 30 per cent in 1997/98 to just over 50 per cent in 2001/02. The brown line in Figure 9.3 also shows that the size of the total market grew five-fold from 9 to 46 million subscribers over this period (from 15 to 78 per hundred population).[3] Unlike many countries which have one or two much larger operators, in the UK there has been healthy jockeying for position, yielding benefits to consumers in keenly priced, decent-quality mobile services.[4]

In the 2000 auction there was a further change to the market structure, with one of the licences reserved for a new entrant (acquired after the auction by H3G, operating with the brand name Three). The UK became a five-player market once H3G launched services in 2003. A decade later in 2010 there was a consolidation back to four operators when EE was created by the merger of Orange and One-to-One (which in the intervening years had become T-Mobile). After that, a four-player market of EE, H3G, Telefónica, and Vodafone was maintained, assisted by competition measures in auctions including spectrum reservation in 2013. Outside the auctions, a competition authority decision in 2016 blocked a proposed mobile merger between H3G and Telefónica (which would have reduced the market to three operators).[5] Other mergers were cleared, such as BT acquiring EE in 2016 and H3G acquiring a small wireless operator, UK Broadband, in 2017.[6]

Access to spectrum is necessary but usually not sufficient for a new operator to be successful. Additional regulation could assist an entrant to meet the challenges of customer acquisition and substantial sunk-cost investments in a new network. For example, the entrant via spectrum in the 2000 auction, H3G, was also supported by a requirement on incumbent operators to offer 2G wholesale national roaming. H3G could then provide 2G services seamlessly to its retail customers to mitigate coverage gaps in its own network. The regulation lasted for some years, but was a transitional measure in order to avoid the regulatory failure risks of an inefficient operator becoming overdependent on regulation to prop it up. Similarly, national roaming was a supporting measure used in Portugal's 2021 auction to assist new entry.

Retail competition in the UK is not only about the four national mobile network operators. As well as competing in the retail market themselves, these incumbents all supply wholesale services to mobile virtual network operators (MVNOs), that is, firms which sell their own branded mobile telecoms services to customers, while relying on the infrastructure of one of the major incumbents. MVNOs form an active market segment which increased from 9 per cent of subscribers in 2001 to 17 per cent in 2018.[7] Both the sector regulator and competition authorities have viewed healthy competition from the four national network operators as benefitting consumers directly through retail competition between them, and indirectly via rivalry to supply wholesale services to MVNOs.

9.2 Competition assessment framework

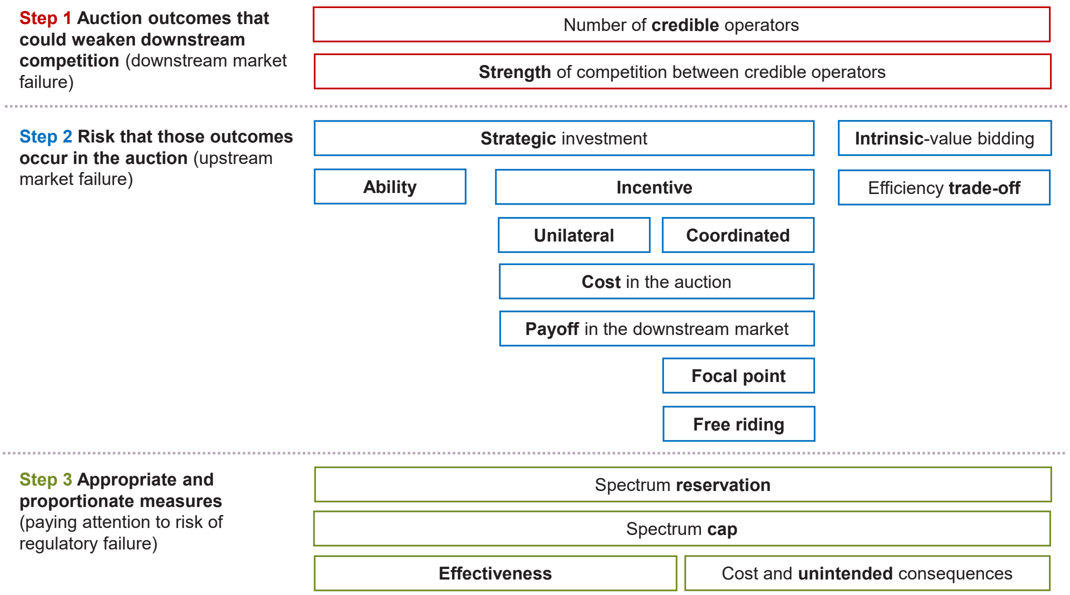
The UK regulator's competition assessment framework for spectrum auctions has drawn on standard techniques and approaches for antitrust analysis, but tailored it to the auction context. Figure 9.4 shows the three-step framework initially developed for the 2013 auction and maintained subsequently. Step 1 (in red) identifies auction outcomes that might lead in the future to downstream market failure, by weakening competition to the detriment of consumers in the short or long term, taking into account operators' pre-existing spectrum holdings. Step 2 (in blue) assesses the risk of upstream market failure of each of those outcomes occurring in the auction itself, in the absence of competition measures. Step 3 (in green) considers possible competition measures that might address the identified concerns in appropriate and proportionate ways, paying attention to their risks of regulatory failure.

Market conditions and other circumstances can change markedly between auctions. So, although the framework is applied consistently, each competition assessment is specific. Auctions contain different spectrum bands that are more relevant to particular dimensions of competition, such as providing coverage or expanding capacity. The spectrum useable for mobile services has increased over time with developments in technology and spectrum policy decisions (see Section 6.1).[8] For example, the pool at the time of the UK's 2000 auction comprised 332 MHz of spectrum, of which 120 MHz (36 per cent of the total) was awarded. Two decades later the mobile spectrum pool was over three times bigger at 1,117 MHz, so that the larger spectrum amount auctioned in the 2021 auction (200 MHz) was only 18 per cent of the total.

Step 1 – Will auction outcomes risk competition concerns from a change in the number of credible operators, and/or a change in the strength of competition between them?

After a spectrum auction a firm could end up with less than the minimum spectrum portfolio needed to be a credible operator, one capable of exerting an effective constraint on rivals across a *wide range*

Figure 9.4. The three steps in the UK's competition assessment framework



Source: Author from Ofcom auction documents.

of mobile services and customers. For example, after the UK's 2013 auction the smallest incumbent operator, H3G, could have ended up with less than the minimum spectrum portfolio it needed to remain a credible competitor. Such a minimum portfolio would provide sufficient capability in: (i) capacity and average data rates; and (ii) quality of coverage.[9] This theory of harm led the regulator to reserve spectrum in the auction (after also assessing steps 2 and 3).

Of course, the competitiveness of a market depends on many more factors than just the number of competitors. Accordingly, the empirical relationship between the number of players and consumer welfare is context dependent, especially when comparing outcomes from competition between three or four credible operators. This question has been contested in a range of merger decisions throughout the world. The relationship of more competitors to lower prices is clearer – both in theory and empirically – than the more ambiguous effects on investment or quality.[10] Spectrum auctions provide a potential opportunity for market entry, given the necessity of suitable spectrum. In some cases, regulators may seek to use auctions as a vehicle to increase the number of network competitors, as in the UK in the 2000 auction (although downsides should also be considered, including risks of excessive intervention under step 3). The question in the next auction in 2013 was the opposing risk of a decrease in competitors – a four-player market with high barriers to entry becoming a three-player market, as a consequence of the outcome of a spectrum auction making an operator unsustainable. Such a result would be a substantial and serious change, without facing the intensive and fact-specific investigation by the competition authorities that would apply to a merger. It seems wise, therefore, to avoid such an outcome via the auction, without precluding any post-auction merger activity that would face the requisite merger assessment.

A second concern is that substantial asymmetry in spectrum holdings between firms could lead to weaker competition for a particular *sub-set* of services or customers, such as highly data-intensive users.[11] For instance, before the 2013 auction EE had the largest share of spectrum – too much spectrum asymmetry after the auction could have meant that one or more of the other credible operators would have been at a disadvantage competing against EE for highly data-intensive customers. For this second theory of harm the regulator set a cap on total spectrum holdings (comprising pre-existing holdings plus spectrum acquired in the new auction).

The concern that spectrum asymmetry could adversely affect competition in a sub-part of the market is likely to be less serious than the loss of a credible competitor.[12] More fundamentally, the inherent desirability of spectrum symmetry between competing operators remains an open question. Asymmetry could lead to weaker competition from operators with smaller holdings, and reduce head-to-head rivalry. Alternatively, asymmetries could allow operators with large holdings to offer better quality services to more customers, or stimulate competitors to adopt more differentiated commercial strategies that could widen consumer choice. An example of a regulatory decision consciously leading to asymmetry was Ofcom's 2012 modification of EE's spectrum licence to allow it to use its 1800 MHz spectrum for 4G. Rival operators only gained access to spectrum to launch their own 4G offerings later on, such as by acquiring 4G spectrum in the 2013 auction. EE launched its 4G services in October 2012, while Telefónica and Vodafone only did so in August 2013, and H3G in December 2013. This asymmetry may well have stimulated faster UK rollout of 4G (although a rigorous causal assessment of the effect of asymmetry has not been undertaken). Instead of all operators delaying the cost of rolling out the new technology, a competitive dynamic occurred where EE sought to obtain a 4G lead and stay ahead, stimulating its rivals to catch up. The asymmetry did not lead to a particular disparity in subscribers between firms, because most growth in 4G subscribers occurred after all four operators launched 4G services. However, years later in 2020 spectrum asymmetries still seemed to be reflected in commercial strategies, such as EE continuing to offer the fastest download speeds.[13]

Another reason for not seeking to impose spectrum symmetry is that operators have alternative ways to increase network capacity – for example, building additional base stations and using more efficient technology. The UK experience shows the potential for firms' downstream market shares to depart from their shares of spectrum holdings. Since 2010 the two largest operators by number of subscribers have been EE and Telefónica. Yet their shares of spectrum have been very different. Both had a similar share of network subscribers (33 per cent) in 2016, but EE's spectrum share (42 per cent) was three times larger than Telefónica's (14 per cent).[14]

In general, there is no rigid relationship between the degree of spectrum asymmetry and the impacts on downstream competition and outcomes for consumers. However, spectrum asymmetries can go too far and lead to unmatchable competitive advantages for operators with large spectrum shares. Or there can be restrictions on the competitiveness of operators with small spectrum shares (for example, the marginal cost of expanding capacity through alternatives to spectrum could make it more profitable for them to compete less strongly).

Step 2 – Are the potential harmful outcomes likely to occur in the auction or not? And what types of auction bidding can raise competition concerns?

If an operator needs to win spectrum in the auction in order to remain competitive, it may be able to acquire it without any competition measures being imposed. But there are two sources of potential upstream market failure. There could be circumstances where one operator (for example, H3G in the UK in 2013) is outbid through *intrinsic-value bidding* by rivals, resulting in reduced competition. A potential reason is differences in operators' private intrinsic values, the profit they expect to derive from the spectrum, which do not take account of the benefits to consumers from increased downstream competition.[15] There is an efficiency trade-off for the regulator to consider. Allocating spectrum to H3G in 2013 when another operator has higher intrinsic value could enhance output efficiency by creating greater downstream competition. However, it could reduce auction efficiency, and potentially damage output efficiency as well by denying the spectrum to the highest-value bidder, who could use it to offer more or better-quality services to its potentially large customer base.

A second source of upstream market failure is that an operator could fail to acquire the spectrum it needs for its downstream competitive position because of *strategic investment* by one or more of its rivals. Rivals could use a foreclosure strategy designed to weaken competition, by bidding above their intrinsic values in order to deny spectrum to the vulnerable operator (such as H3G in 2013).[16] Successful strategic investment involves no efficiency trade-off and is unambiguously an undesirable outcome, worsening output efficiency. Like many other foreclosure concerns in antitrust regulation, the risk can be analysed in terms of the ability and incentive.[17] The ability to foreclose depends on whether it is feasible for the strategic investor(s) to acquire the spectrum needed to deny it to the victim, and thereby restrict downstream competition. Such analysis can highlight specific spectrum acquisition patterns that would need to occur for there to be a foreclosure effect. The incentive depends on the balance between the cost in the auction to the strategic bidder and its expected payoff in downstream markets (comprising both the retail market and the wholesale market for sales to MVNOs).

The strategic investment could be undertaken by a single bidder acting *unilaterally*. The strategic investor's cost is the excess of the price it has to pay to acquire the spectrum over its intrinsic value. The auction price is set by the victim's intrinsic value, which the strategic investor must outbid. If the spectrum is important to the victim's competitive position, as is especially the case if its credibility is at stake, then the victim has a relatively high intrinsic value and so strategic investment is more costly. The payoff is the strategic investor's expected gain from a reduction of competition in downstream markets, which depends on the extent to which the victim is weakened as a competitor and the causally related increase in profit. For example, the victim may be capacity-constrained or unable to match the quality of service of competitors, leading to its customers switching away. The strategic investor's expected payoff depends on the profitable customers it can acquire, and any price increase it can make once there is weaker competition in the market. In a four-player market, customers switching away from the victim operator (H3G in our 2013 example) have a choice of three other networks. Therefore, the unilateral strategic investor cannot expect to obtain all these customers – the two other operators would also benefit, despite not incurring any of the costs of this strategy. Similarly, if the strategic investor can increase its prices in the downstream market, the two other operators are also likely to be able to do so. In other words, these operators can freeride on the strategic investor.

Generally, the cost and the payoff are correlated. The more that strategic investment weakens the victim, the higher the cost is likely to be. Although correlated, the overall profit gain from weaker competition can be larger than the cost of strategic investment, because industry profits are generally larger in a less competitive market (for example, a monopoly in the extreme).[18] However, since a unilateral strategic investor incurs all of the costs but obtains only some of the payoff, this reduces the incentive to engage in the foreclosure strategy. The cost can also exceed the payoff because the strategic investor has to outbid the victim's marginal value. It might have to do so on a relatively large amount of spectrum beyond its own intrinsic value.

This takes us to the possibility of *coordinated* strategic investment by multiple bidders 'ganging up' on a weaker rival. Here, the incentive is increased because the cost is shared among multiple strategic investors. However, the coordination needs to be achieved successfully (and legally).[19] Each strategic investor has an incentive to engage in freeriding, avoiding the cost but still receiving a proportion of the payoff, making coordination more difficult to achieve. But it is made easier if the auction circumstances provide a clear focal point, obvious to all the coordinating players. An example of a possible focal point in the UK's 2013 auction was three strategic investors each acquiring 20 MHz of the 60 MHz available in the 800 MHz band, in order to deny it to H3G. An equal amount of spectrum would not necessarily mean an equal cost for each strategic investor. Some could have had lower intrinsic values for the 800 MHz band, and so faced a higher cost of strategic investment (and some could have faced no cost at all if they had the highest intrinsic values). But with this focal point, each strategic investor would know that if it did not go through with its part of the strategy, the foreclosure effect would not be achieved, so it would not obtain the payoff.

It is unlikely that the regulator can accurately quantify all of these effects. But it can reach an informed judgement about the risk of adverse outcomes by applying the framework of considerations in Figure 9.4 to the applicable circumstances of the auction and market conditions. The auction outcome arising from intrinsic-value bidding involves a trade-off between different types of efficiency. The risk of unilateral or coordinated strategic investment can be evaluated by considering the cost, expected payoff, focal point, and potential for freeriding. The UK regulator's analysis for the 2013 auction led it to take seriously the risk of the focal point for strategic investment in the 800 MHz band as part of its case for imposing spectrum reservation in the auction. In other cases, the step 2 analysis can help the regulator to avoid basing any competition measures on outcomes that are very unlikely to occur (such as rejecting sub-caps in the 2021 auction, as explained in the next subsection).

The regulator can also influence the risk of strategic investment through the auction design in at least two ways:

- Information policy: Revealing less information to bidders can make it harder for strategic investors to know whether they are targeting the victim or just competing against rivals who are not vulnerable, or whether other parties in an attempted coordinated strategy are doing their part. If a potential strategic investor faces a greater risk of incurring the cost without obtaining the payoff, foreclosure is less attractive.
- Auction format: Strategic investment is generally more costly for strategic investors in auctions using the SMRA than the CCA format. Bidding for more spectrum increases the price of all lots bought in the SMRA. A strategic investor also faces a risk of bidding for a large number of lots at a price above its intrinsic value, but only winning some of them and failing to achieve the foreclosure effect. By contrast, in the CCA format, the package bid either wins or loses in its entirety. In addition, with non-linear pricing, bidding for a larger package does not necessarily increase the price of a smaller package or infra-marginal lots. (This is the other side of the coin of the CCA being less prone to demand reduction – see Section 8.3).

Other options for regulation could potentially affect the payoff from foreclosure. For example, strategic investors might expect a regulator clearly committed to promoting competition to respond to successful foreclosure in an auction by introducing tighter regulation afterwards. Or successful strategic investment might make the regulator more likely to reserve spectrum for a new entrant in a future auction. Both regulatory threats could shorten the duration of the foreclosure effect and so reduce the expected payoff.

Step 3 – What types of competition measures are proportionate and appropriate?

Spectrum caps are a common competition measure and can be implemented by regulators in different ways. A cap can limit how much spectrum in a specific band can be acquired by any one bidder in the auction, as in the UK's 2000 auction when bidders could win at most one licence. Alternatively, a cap can restrict the total of any operator's pre-auction holdings plus the spectrum it acquires in the auction, as in the UK's 2013, 2018, and 2021 auctions. Or, a cap can apply to a subset of spectrum, such as the cap on low-frequency spectrum (especially valuable for coverage) which also applied in the 2013 auction.

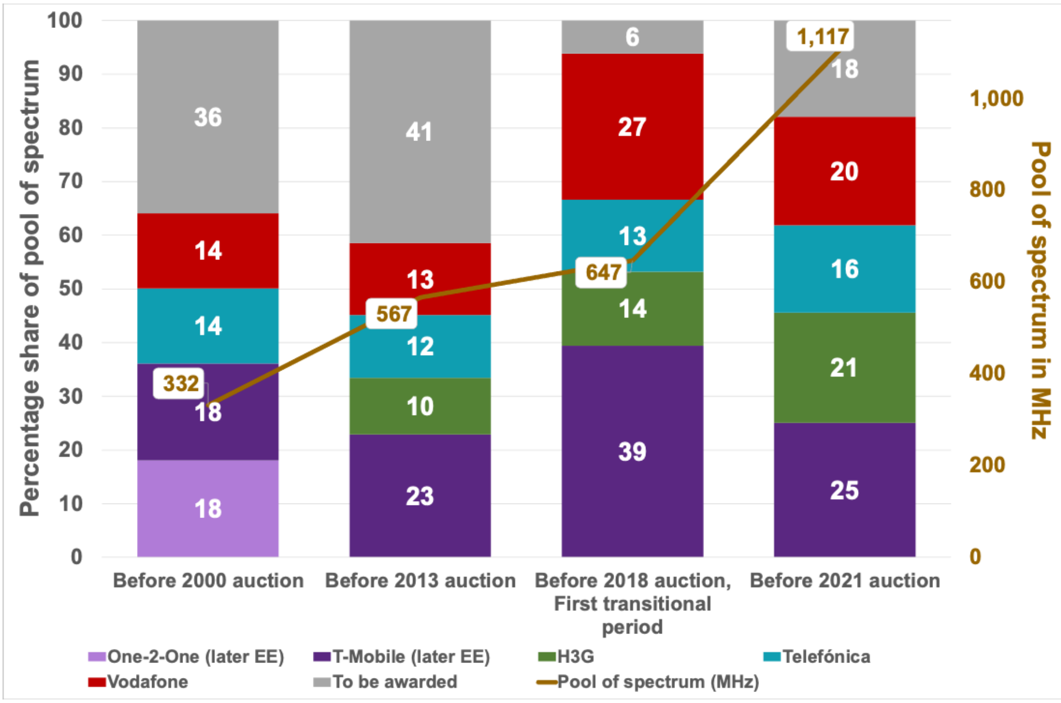
The other main measure is spectrum reservation, which splits operators into those eligible to bid for reserved spectrum and others who can only bid for unreserved categories.[20] For example, in the 2000 auction all bidders could compete to win one of four licences, but only new entrants were permitted to bid for the fifth, reserved licence. With a restricted set of bidders, reserved spectrum usually sells at a lower price than similar unreserved spectrum, as occurred in the 2000 and 2013 auctions. (However, an exception in Australia is discussed in the next section.)

Any analysis of the appropriateness of these types of competition measures to address the potential harms should also consider the potential costs and risks of regulatory failure, especially where undesired outcomes are unlikely to occur. The disadvantages of measures include whether they can be effective in combatting the specified competition concerns, and potential unintended consequences. For instance, imposing caps may reduce the economic efficiency of the auction's spectrum allocation, a risk that increases with the restrictiveness of the cap. Most disadvantages are reduced if the measure is limited to the minimum needed to address the concern. More interventionist regulation like spectrum reservation comes with a risk of correspondingly greater detriment, because it denies the spectrum to existing operators who could use it to expand or improve their services to consumers. Such a measure is generally only considered appropriate to address serious concerns about the number of credible operators. Other potential unintended consequences include: unsold or underutilised spectrum; losing downstream competition and innovation benefits from asymmetric spectrum holdings; operators modifying their bids to influence future regulatory decisions; and the level of the cap acting as a focal point to make coordinated strategic investment in the auction easier.[21]

On the risks to credible competitors, Figure 9.5 shows the spectrum shares of mobile operators before each UK auction, highlighting how much was at stake in 2000 and 2013 when 36 per cent and 41 per cent of total spectrum was to be awarded. On both occasions the regulator assessed a significant risk of undesirable outcomes occurring through intrinsic-value bidding or strategic investment, and imposed the spectrum reservation detailed in Figure 9.2 and Annex A1.[22] Later auctions in 2018 and 2021 did not raise the same credibility concerns, so that there was no spectrum reservation. The brown line in Figure 9.5 also shows the large increase in the pool of spectrum for each successive auction competition assessment.[23] As well as reducing the likelihood of credibility concerns, because of each operator's larger spectrum portfolio, it emphasises the importance of making the analysis forward-looking.

Of course, the number of operators is also affected by merger and acquisitions activity amongst operators. The assessments of UK mergers made by the competition authorities covered a range of retail and wholesale questions, with spectrum issues sometimes being prominent. For example, the EE merger in 2010 was cleared by the competition authorities with remedies including spectrum divestment – EE had to divest 30 MHz of the 1800 MHz band, which it sold in 2012 to the rival firm H3G.[24]

Figure 9.5. Spectrum shares before UK auctions with differing degrees of asymmetry, and the growing pool of spectrum for competition assessment



Source: Author from Ofcom auction documents.

Turning to the strength of competition between operators and spectrum asymmetry, all operators need to be able to expand capacity, given the rapid growth in mobile data. In considering total spectrum caps, what is the threshold level of asymmetry that leads to sufficient concerns to require action? There is no simple or clear-cut answer. One pragmatic benchmark is a 40 per cent spectrum share for the operator with the most spectrum, because in a four-player market it would have double the average share of its three competitors. The UK regulator used a 37 per cent threshold, the level at which it first set the total spectrum cap in the 2013 auction, and then subsequently in the 2018 and 2021 auctions. This is not a 'magic' number, and other thresholds could also be reasonable, but maintaining a consistent approach can have benefits of regulatory certainty. Figure 9.5 shows that the spectrum shares between the four operators were relatively symmetrical before the 2000 and 2021 auctions, compared to much greater asymmetry before the 2013 and 2018 auctions. Accordingly, while spectrum caps were imposed in all four auctions, there were especially significant competition concerns about spectrum asymmetry in 2013 and 2018.

Caps on subgroups of spectrum are based on other theories of harm. For example, the concern that led to the sub-cap on low-frequency spectrum in the 2013 auction was asymmetry in spectrum holdings especially well suited to providing coverage, because two operators (Telefónica and Vodafone) held all the pre-existing low-frequency spectrum (900 MHz band).[25] Signals using lower-frequency spectrum travel further, making it less costly to provide coverage – fewer base stations can be deployed with larger coverage footprints. The primary competition issue in 2013 was indoor coverage because signals at lower frequencies also tend to penetrate inside buildings more effectively (although this depends on a range of other factors as well, including building materials).

In competition assessments for other auctions, the UK regulator rejected calls for sub-caps, such as for either low-frequency or 5G spectrum in the 2021 auction. Applying the framework set out here, Ofcom concluded that the theory of harm was not strong enough to justify extra regulation. In part, this was based on a view in step 2 that operators with less low-frequency or 5G spectrum would be able to acquire it, as indeed subsequently happened (see Annex A5).

In many countries, use of spectrum caps is routine. Reservations to promote new entry are less common, and the experience has been mixed.[26] The UK provides a positive case of a sustainable entrant benefitting consumers through valuable contributions to market competitiveness. In France a new entrant (Free, a subsidiary of Iliad) initially obtained spectrum through set-aside in an administrative allocation. It undercut incumbents' prices and grew quickly in a retail market historically less competitive than the UK, to achieve a market share approaching 20 per cent.[27] However, there are also less successful examples. Set-aside failed to attract new entrants in Austria, the number of mobile operators has gone up and down over the years in the Netherlands, and there have been criticisms of spectrum reservation in Canada.[28] Reservation was used in Portugal's 2021 and Belgium's 2022 auctions, leading to two new entrants, but the overall success in promoting competition is not yet evident at the time of writing (in 2022).[29] To see how the framework can be applied to future circumstances or in different countries, the next section looks at an Australian case.

9.3 Cap and set-aside measures in Australia's 2021 auction

Australia's 2021 auction included a cap on low-frequency (sub-1 GHz) spectrum holdings and set-asides for two incumbent operators. At the time, Australia's mobile operators were Telstra (42 per cent retail market share), Optus (26 per cent), and TPG (17 per cent) – while the remaining 15 per cent was accounted for by MVNOs.[30] The auction included 70 MHz of low-frequency, paired spectrum comprising 20 MHz in the 850 MHz 'expansion' band and 50 MHz in the 900 MHz band. Three public organisations with regulatory functions were involved in the auction. The competition authority, the Australian Competition and Consumer Commission (ACCC), provided advice. The decision on competition measures was then made by the responsible minister, who directed the spectrum regulator, the Australian Communications and Media Authority (ACMA), to implement them in the auction. The minister decided to impose a cap on sub-1 GHz spectrum broadly in alignment with the ACCC's advice. But another decision was to set aside spectrum for two of the incumbent mobile operators (Optus and TPG), against the advice of the ACCC.[31]

Sub-1 GHz cap

For the sub-1 GHz spectrum cap, the ACCC in effect analysed steps 1 and 3 of the framework. Before the auction, Optus had 20 MHz of low-frequency spectrum, whereas Telstra held 60 MHz and TPG 50 MHz.[32] Under step 1 (downstream competition concerns), the ACCC concluded that, because Optus had the smallest pre-auction low-frequency holdings, its ability to compete would be constrained if it did not acquire more sub-1 GHz spectrum in the 850/900 MHz auction. This reference to a constrained ability to compete suggests that strength of competition between operators from spectrum asymmetry was the concern, rather than Optus's credibility being at risk (although the ACCC did not make this distinction).

The public version of the ACCC's analysis contained no articulated discussion for step 2, the risk of the harmful outcomes occurring in the auction. Under intrinsic-value bidding, without competition measures, Optus failing to acquire spectrum could represent an upstream market failure. However, this would involve a judgement about the trade-off between auction and output efficiency. If the ACCC was concerned about strategic investment, a coordinated strategy seemed a more significant risk than a unilateral approach. Strategic investment coordinated between Telstra and TPG might well have provided a large enough combined expected payoff to offset the cost. The issue would be whether a focal point would enable Telstra and TPG to coordinate to acquire all the spectrum in the auction between them, and each obtain a reasonable net payoff. Two possible focal points for the 70 MHz available in the auction could be 40/30 or 50/20, with Telstra acquiring the bigger amount, given its larger expected payoff due to its much greater retail market share (42 per cent vs TPG's 17 per cent).[33]

By contrast, unilateral strategic investment could be costly, given Optus's high intrinsic value for the spectrum it would need to remain a strong competitor, thus requiring a commensurately large expected payoff to the strategic bidder. Telstra would be the more likely unilateral strategic investor because it might expect a larger payoff from weakened competition. But if Optus could outbid TPG, Telstra would need to acquire a large amount of spectrum. In the limit Telstra would need to acquire all 70 MHz in the auction to prevent Optus from acquiring any spectrum.[34]

Under step 3 of the framework, the ACCC concluded that a cap on sub-1 GHz spectrum of 40 per cent or 80 MHz would promote competition and investment. This cap would restrict Telstra to 20 MHz and TPG to 30 MHz or less, and so ensure that Optus could acquire at least 20 MHz in the auction (assuming it could outbid any other bidders). However, there was no explicit discussion of regulatory failure risks.

Why did the 2021 auctions in Australia and the UK treat caps on the sub-1 GHz spectrum differently, despite the regulators apparently using quite similar analytical frameworks? Compared to the UK, 'regional Australia' has a much more extensive, less densely populated geographic landmass (outside major population areas), where the advantages in wider area coverage provided by sub-1 GHz spectrum are especially important. Although there is a superficial similarity in having a cap level of around 40 per cent in both countries, in Australia's three-player market this constrained the distribution to be relatively more symmetric than required in the UK. The corresponding pragmatic logic in the UK of limiting the operator with the largest holdings to double the average of its competitors would imply a looser limit of 50 per cent. The ACCC provided little specific justification for the 40 per cent cap to restrict spectrum asymmetry. However, these are matters on which there is no definitive number, and it falls within a reasonable range for judgement about balancing the risks of market and regulatory failure. The minister broadly accepted this advice and directed the ACMA to impose a sub-1 GHz cap.[35]

Set-aside for Optus and TPG

The set-aside measures in Australia's 2021 auction were not about promoting new entrants. Instead the theory of harm related to Optus and TPG relying on the 900 MHz band for their 3G services.[36] This spectrum was already in use by the operators but was due to be cleared by 30 June 2024, and would be reallocated in the 2021 auction for use after that date. The concern was that any failure of Optus and TPG to reacquire at least 10 MHz in this band would jeopardise the policy objective of continuity of service for their customers, especially in regional areas. The ACCC characterised this concern as primarily a competition issue, because an operator failing to provide service continuity could see the loss of its customers to rivals. So, 'Optus and TPG would have strong incentives to ensure that their customers would not experience service disruptions'.[37] The ACCC concluded that set-aside was not needed because the proposed sub-1 GHz cap would promote the policy objective by allowing both firms a reasonable opportunity to acquire some 900 MHz spectrum. An economic efficiency advantage would follow from allowing the auction 'to determine the value that Optus and TPG place on the ability to continue to provide existing services in the band'.[38] These points effectively fall under steps 2 and 3 of the framework.

The minister's explanatory statement disagreed with the ACCC's conclusion, but did not bring in any considerations additional to its analysis. Instead the minister reached a different judgement placing more weight on the risk to service continuity.[39] Three important aspects in the framework in Figure 9.4 were omitted in the minister's statement. The forward-looking scale of the concern (under step 1) was unclear. For example, there was no analysis of the number of customers that would still rely on 3G services in Australia by mid-2024 when the old 900 MHz licences ran out, taking account of any mitigating steps that Optus and TPG would have time to implement (such as migrating their customers to 4G devices).

A second omission was assessing upstream market failure: the risk that Optus or TPG would fail to acquire the spectrum they apparently needed for 3G service continuity (step 2 in the framework). This risk looked to be especially small because, with the sub-1 GHz cap in place, it was not feasible for Telstra to prevent both Optus and TPG from acquiring 10 MHz each. Recognising that both the 850 MHz and 900 MHz bands could be used for 3G, Telstra would have needed to acquire all 70 MHz in the auction – yet the cap limited Telstra to acquiring at most 20 MHz. There was an argument for focusing just on the 900 MHz band, given that the 850 MHz band may have been an imperfect substitute involving additional cost for 3G use (such as equipment changes). Even so, the cap prevented Telstra from acquiring the amount needed for successful strategic investment (more than 30 MHz of the 50 MHz available).

In effect, therefore, the set-aside was protecting Optus from TPG and vice versa, and not from the largest operator, Telstra. For example, it was theoretically possible for Optus to be denied 10 MHz. But it would have required Telstra and TPG to acquire all 70 MHz, by Telstra winning its maximum 20 MHz under the cap and TPG obtaining 50 MHz (or considering only the 900 MHz band, Telstra 20 MHz and TPG 30 MHz). This scenario would have involved TPG taking on a bigger share of any coordinated strategic investment against Optus. The expected payoff would have needed to be large enough to justify the cost of purchasing spectrum above its own intrinsic value (and this cost was likely to be higher in 900 MHz than 850 MHz to the extent it was more valuable to Optus by making service continuity cheaper). The auction regulator ACMA's chosen format was a version of an SMRA, a linear price auction, so that Telstra and TPG would have needed to pay the same high price, in excess of TPG's marginal value for 10 MHz, on all of the spectrum.[40] This would have seemed an unattractive prospect for TPG, especially as Telstra, a much bigger operator, might have gained a larger payoff.

A third omission from the minister's analysis was not assessing any downsides of imposing the set-aside (needed in step 3 of the framework), such as complications and potential unintended consequences from integrating set-aside into the auction design.[41] The ACMA's approach required Optus and TPG to decide whether to take up their set-asides before bidding started, so other bidders would have certainty about the amount of unreserved 900 MHz spectrum they could bid for.[42] The ACMA decided to specify distinctive reserve prices for set-aside spectrum that were 25 per cent higher than the reserve prices for the rest of the band.[43] By definition, this was the final price because there could be no competition for spectrum that was reserved for individual, named operators. However, depending on bidding in the auction, the set-aside price could have turned out to be either lower or higher than the market price of unreserved spectrum, and the ACMA recognised concerns about both eventualities. If the set-aside price turned out to be lower, there could be a competitive advantage to Optus/TPG.[44] If higher, Optus/TPG would be disadvantaged by set-aside, because they would have been better off without it – which is what happened when the auction took place. Only Optus decided to take up its set-aside, and in the event it paid about $50 million extra as a result.[45]

The set-aside in this case can, therefore, be seen as a regulatory failure arising from the minister imposing his own view about both the scale of the 3G continuity issue and the risk of it occurring. The minister's decision that the set-aside was warranted was contrary to the competition authority's assessment, and also substituted for the commercial judgement of the operators which could have been reflected in their auction bids. A possible rejoinder might be that set-aside is a safeguard provision. If it merely imposed an outcome that would have occurred anyway, it should not cause distortions. However, in this case, the result was that set-aside was unnecessary for one of the supposed beneficiaries, TPG, which opted not to take it up, and it made the other 'beneficiary', Optus, worse off.

The Australian example is helpful in showing that gaps in explicit competition assessment can create costs even when established institutions with reputations for high-quality analysis are implementing policy. The exercise of comparing the analysis of the sub-1 GHz cap and set-aside in Australia against the analytical framework reaffirms the value of all three steps in the assessment recommended here. For example, steps 2 and 3 help to clarify what is at stake and the benefits from imposing the competition measure relative to the costs. They can mitigate a potential failing from competition measures that are more restrictive than necessary, which risks distorting the auction outcome for the industry in the upstream market and for the public in the downstream market.

Conclusions

Competition considerations play an important role when using spectrum auctions to award strategic assets in oligopolistic markets. The value of the three-step framework set out in this chapter is to assist in the inclusion of relevant considerations and to organise a process of consistent, structured judgement, while also guarding against adopting ineffective or unduly restrictive competition measures.

Notes

1 Klemperer (2004, chapter 3, p.103).

2 There are limited theoretical and empirical analyses of the relationship between spectrum concentration and consumer welfare. The model of oligopoly competition by Loertscher and Marx (2014) considers the implications of spectrum holdings for reducing network costs, and the model by Lhost, Pinto, and Sibley (2015) for capacity and network quality. The empirical results of Woroch (2020), using data from 700 areas in the USA, show an inverted-U relationship between spectrum concentration and subscriber penetration rates.

[3] Because some consumers had more than one subscription, the proportion of the UK population with a mobile phone was less than 78% in 2001/02. For UK population figures, see Office of National Statistics 'Mid-1851 to Mid-2014 Population Estimates for United Kingdom', https://perma.cc/47Z3-AN28.

[4] See, for example, the detailed analysis in Ofcom (2017, annex 1), and Ofcom (2020a, annex 3).

[5] The H3G/Telefónica merger decision in European Commission (2016) was later overturned by the courts on appeal – see EU General Court (2020).

[6] Competition and Markets Authority (2016, 2017).

[7] Ofcom (2020a, figure A3.4). These subscriber shares include MVNOs with mobile operator ownership, such as Tesco Mobile (a joint venture between Tesco and Telefónica).

[8] Ofcom regarded mobile spectrum as becoming useable once it satisfied three conditions: (i) it was allocated and could be used for mobile services; (ii) there were no major constraints on use (for example, due to co-existence with other spectrum users); and (iii) the device ecosystem was sufficiently developed, such as the band being included in popular smartphones — see Ofcom (2017, paragraph 5.14).

[9] Ofcom (2012b, section 4). Another possible criterion is spectrum that provides an operator with a route to deploying the latest technology, e.g. 5G as noted by Ofcom (2020a, paragraph 4.316).

[10] For studies on the effects of mobile mergers see, for example, Genakos, Valletti, and Verboven (2018), and Ofcom (2020g).

[11] Competition concerns can be identified either with or without a formal market definition exercise. For example, in Australia, discussed in Section 9.3, market definition was included in the analysis. By contrast, Ofcom chose not to define the market for the following reasons (Ofcom, 2012b; paragraph A3.41): its analysis directly assessed competition concerns, it was consistent with a range of possible market definitions whether a single or separate markets, and there was the risk of an artificially binary market boundary given product differentiation and the long forward-looking timeframe.

[12] The distinction between the two types of concern (loss of a credible operator and weaker competition arising from spectrum asymmetry) is one of the tailored aspects in Ofcom's framework compared to standard antitrust analysis. The precise dividing line between these concerns can be a matter of judgement. However, the distinction is useful in capturing a significant difference in expected seriousness of concern and broadly mapping to different competition measures (reservations to address credibility concerns, and caps for spectrum asymmetry concerns).

[13] Ofcom (2020a, annex 5).

[14] Ofcom (2017, figure A1.58b, annex 1).

[15] Myers (2013). One way this could arise is if larger operators already had a degree of downstream market power.

[16] Loertscher and Marx (2014) describe strategic investment as 'warehousing' and formally model foreclosure incentives.

[17] For example, Competition and Markets Authority (2021, section 7).

[18] The strategic bidder's payoff relates to the scenario of a less competitive market, which has been weakened by the strategic investment. However, the victim operator's intrinsic value – and hence the cost of strategic investment – relates to the scenario of a more competitive market without this weakening of competition.

[19] Achieving coordination legally may require implicit or tacit behaviour, because auctions usually have strict rules against *explicit* collusion, including preventing communication of auction-sensitive information between bidders – for an example of a proposed fine for breach of such rules in a 2020 auction in the USA (for rural broadband procurement), see FCC 'FCC Proposes $100K Fine Against LTD for Prohibited Communications', 3 May 2022, https://perma.cc/6T8N-S4BV.

[20] Other possible policy instruments to enhance competition include bidding credits, band plans, auction design, and antitrust enforcement, as discussed by Cramton et al. (2011).

[21] Ofcom (2017, paragraphs 7.45–7.57).

[22] For the 2013 auction, see Ofcom (2012b, section 4 and annexes 2–3).

[23] The analysis for the UK's 2018 auction was complicated by three relevant time periods, of which – for simplicity – only the 'first transitional period' is shown in Figure 9.5 (relevant to the cap on immediately useable spectrum, affecting acquisitions in the 2.3 GHz band). There were larger pools that included spectrum to be awarded not only in 2018 but also 2021 for the 'second transitional period' (916.9 MHz, relevant to the cap on total spectrum, affecting acquisitions in both auction bands), and for the 'longer term' (1,116.9 MHz). For a detailed explanation, see Ofcom (2017, section 6).

[24] European Commission (2010).

[25] The sub-cap was set at 42 per cent of low-frequency spectrum. Given pre-existing spectrum holdings, the size of each lot of the 800 MHz band in the auction (10 MHz) in effect offered a practical choice between setting the level of the sub-cap at 35 or 42 per cent. Ofcom decided to adopt the latter, less restrictive approach.

[26] For example, for caps on low-frequency spectrum in 15 European countries, see Cave and Nicholls (2017, table 1). For an indication of CCAs that included caps and/or reservation, see Mochon and Saez (2017).

[27] See MuniWireless 'Iliad-Free gets fourth mobile license in France, plans innovative pricing and services', 20 December 2009, https://perma.cc/UMD3-XH8A, and Wikipedia 'Free Mobile', https://perma.cc/7S9T-CGPR.

[28] See criticism before Canada's 2008 auction by Crandall and Ingraham (2007), and afterwards by Hyndman and Parmeter (2015).

[29] In Portugal's 2021 auction, six bidders won spectrum: the three incumbents (NOS, MEO, Vodafone), an operator with an existing wholesale 'neutral host' business model (Dense Air), and two new entrants (Dixarobil and Nowo). The entrants won 95 and 70 MHz of spectrum, comprising both set-aside spectrum (in the 900 and/or 1800 MHz bands) in the 'new entrant

stage' and unreserved spectrum (in the 2.6 GHz and 3.6 GHz bands) in the main stage of bidding – see ANACOM 'Results of auction bidding phases', 27 October 2021, https://perma.cc/2XUK-LHSA. In Belgium's 2022 auction, five operators won spectrum including two newcomers, one of which (Citymesh) obtained 110 MHz of spectrum, comprising 60 MHz of set-aside spectrum (in the 700, 900, 1800, and 2100 MHz bands) and 50 MHz of unreserved spectrum (in the 3.6 GHz band) – see Belgian Institute for Postal Services and Telecommunications 'Radio spectrum auction raises 1.2 billion euros', https://perma.cc/8PV5-CHSX.

30 ACCC (2020).

31 See ACCC (2021), and Australian Government: Department of Infrastructure, Transport, Regional Development, Communication and the Arts 'Allocation limits for Australia's next 5G spectrum auction', 9 August 2021, https://www.infrastructure.gov.au/department/media/news/allocation-limits-australias-next-5g-spectrum-auction.

32 These were holdings in major population areas, while in regional areas Telstra had 10 MHz more and TPG 10 MHz less – see ACCC (2021, figure 2).

33 Although it was not inevitable that diversion ratios for customers switching away from Optus to competitors would be in alignment with 2019–20 market shares, they provided a useful reference point.

34 To the extent that the 850 MHz band was an imperfect substitute for 900 MHz spectrum (such as due to differences in geographic configurations), acquiring a large amount of the 900 MHz band could have been sufficient to weaken Optus as a competitor.

35 The minister's decision varied the cap between 40% (82 MHz) in major population areas and 45% (92 MHz) in regional areas.

36 In 2021 Optus also used its 900 MHz spectrum for 4G services on some of its sites. But the focus here is on 3G continuity, as 4G services were not reliant to the same extent on 900 MHz.

37 ACCC (2021, p.19).

38 ACCC (2021, p.20).

39 Fletcher (2021).

40 The version of SMRA was described as enhanced or 'ESMRA' – see ACMA (2021c).

41 ACMA (2021a).

42 ACMA (2021b), and ACMA (2021c).

43 ACMA (2021b).

44 ACMA (2021a, p.37).

45 Optus paid $66 million more for set-aside in major population areas (where unreserved spectrum sold for the 20% lower starting price) and $13 million less in regional areas – see ACMA 'Spectrum allocation and auction summary – 850/900 MHz band (2021)', https://www.acma.gov.au/spectrum-allocation-and-auction-summary-850900-mhz-band-2021.

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10. Harnessing auctions for better-informed public policy decisions

Summary

- Auctions can help to elicit market information that is otherwise hard to obtain and can improve public policy decisions.
- Where there is a choice between alternative spectrum that can be reserved to promote competition, utilising auction bidding can assist in deciding the more economically efficient option (thereby mitigating the regulatory failure of the regulator having to make a less informed decision before the auction). This approach was implemented in the UK's 2013 auction through the use of flexible reservation ('spectrum floors').
- Auction bids can also be used to provide information on the costs of coverage obligations, enabling a better understanding of the balance between their costs and benefits.

The information usually elicited by auction bids relates to deciding the identity of the winning bidders in the auction and the prices to be paid. By examining actual and proposed examples in the UK, this chapter shows how auctions can also be designed to incentivise auction bidders to reveal other valuable information which might otherwise be difficult or impossible to obtain. Public policy decisions often involve weighing up pros and cons, or costs and benefits. The examples show how information drawn from auctions can illuminate different parts of a cost-benefit analysis, including the opportunity cost of policy alternatives.

With an objective of economic efficiency, the regulator seeks to design the auction to obtain accurate information through straightforward bidding. Fully achieving this is difficult due to auction design complications and the scope for strategic bidding. Nevertheless, auctions can often be designed to provide reasonable incentives. If so, they can yield good evidence that would otherwise be lacking, as for deciding how much of the band to clear in the USA's incentive auction in 2016–17 (see Section 6.1): 'the novel two-sided broadcast auction successfully reallocated 84 MHz of prime

How to cite this book chapter:

Myers, Geoffrey (2023) *Spectrum Auctions: Designing markets to benefit the public, industry and the economy*, London: LSE Press, pp. 185–195. https://doi.org/10.31389/lsepress.spa.j.

spectrum, raised almost $20 billion in gross revenue, compensated winning television stations, and deposited $7.3 billion in the Federal Treasury'.[1] The first section considers how reserving spectrum flexibly can help improve the economic efficiency of regulatory interventions, and the second section then looks at eliciting more accurate views from mobile providers about their costs of providing different levels of coverage.

10.1 Flexible spectrum reservation: mitigating regulatory failure

In the UK's 2013 auction the regulator Ofcom had a choice of spectrum bands to reserve in order to promote downstream competition, but was uncertain which would be more efficient. Ofcom considered it was important to maintain downstream competition between four credible operators, but one firm (H3G, the smallest incumbent) was at risk. Ofcom identified different minimum spectrum portfolios which could be reserved to provide the required capability for a fourth credible operator to be sustainable – either H3G or a new entrant. The alternatives were either a smaller amount of higher-value *coverage* spectrum in a low-frequency band, or a larger amount including higher-frequency *capacity* spectrum. But each of these alternative portfolios was also different between the two types of eligible bidder for reserved spectrum, because a new entrant without any pre-existing holdings would have needed more spectrum than H3G, especially low-frequency spectrum in order to build new national coverage.[2]

The usual method would be for the regulator to pre-specify the spectrum to be reserved (set-aside). However, this would require two levels of regulatory choice. The first decision would be whether to pick a spectrum amount for a new entrant or for H3G, since these were different. The second decision would be whether to favour reserving coverage or capacity spectrum. In an impact assessment, the analytical problem would be to balance the costs and benefits for each decision. Would the additional opportunity costs of reserving a larger amount of spectrum needed by a new entrant justify the incremental competition benefits compared to reserving spectrum for H3G? And which of the coverage or capacity spectrum requirements would achieve a better trade-off between the competition benefit and the opportunity cost of denying use of the reserved spectrum to other operators, the larger incumbents? A proxy for this second question was the balance between the value of each spectrum requirement to the beneficiary (H3G or new entrant) and the opportunity cost to other bidders. (It was a proxy because it would reflect the values to operators, not final consumers, even if there was likely to be a correlation between the two.) The values and opportunity costs depended on private information held by the operators which was not and could not be known by the regulator. Firms' self-interest meant that they did not generally have the incentive to provide this information.

Exploiting the potential of auctions to elicit private information, Ofcom chose a flexible reservation solution using 'spectrum floors' instead of setting aside pre-specified spectrum. The CCA format used in the 2013 auction allowed operators to bid for many different packages of spectrum. Each bidder eligible for the reserved spectrum made mutually exclusive bids for its alternative spectrum floors. The difference between these bid amounts was that operator's incremental bid value to prefer one package of reserved spectrum over the other – this was the benefit side of the equation. The cost side was derived by comparing different package bids made by other operators. They could place bids for all the spectrum in the auction, even though some of it would ultimately be reserved for the winning eligible bidder. So the relevant combinations of their various package bids identified their combined bid values for each spectrum floor which they could be denied the opportunity to acquire. The difference between these bid values for the spectrum in the different floors was therefore the opportunity cost of one floor being reserved instead of the other. The choice of reserved spectrum from among the specified options was then determined as the spectrum floor, which optimised the net effect between the positive incremental bid value to the eligible bidder and the negative opportunity cost to other bidders. The approach of spectrum floors was designed to mitigate the regulatory failure that could have arisen under simple set-aside from the regulator choosing the wrong spectrum to reserve, i.e. involving a worse balance between costs and benefits.

The choice of minimum or reserve prices also helped to mitigate another type of regulatory failure. Ofcom set the reserve price for the more valuable, low-frequency band (800 MHz) closer to expected market value than its usual practice, in order to manage the trade-off between auction efficiency and the promotion of competition. The higher reserve price required substantial financial commitment to bid for spectrum floors – £225 million for H3G, and £480 million for a new entrant. Although far from a guarantee, this level of commitment mitigated the risk that reserved spectrum might be won by an operator that would only have a limited impact on competition, not justifying the probable loss in auction efficiency from reserving the spectrum and thereby denying it to the larger incumbents.

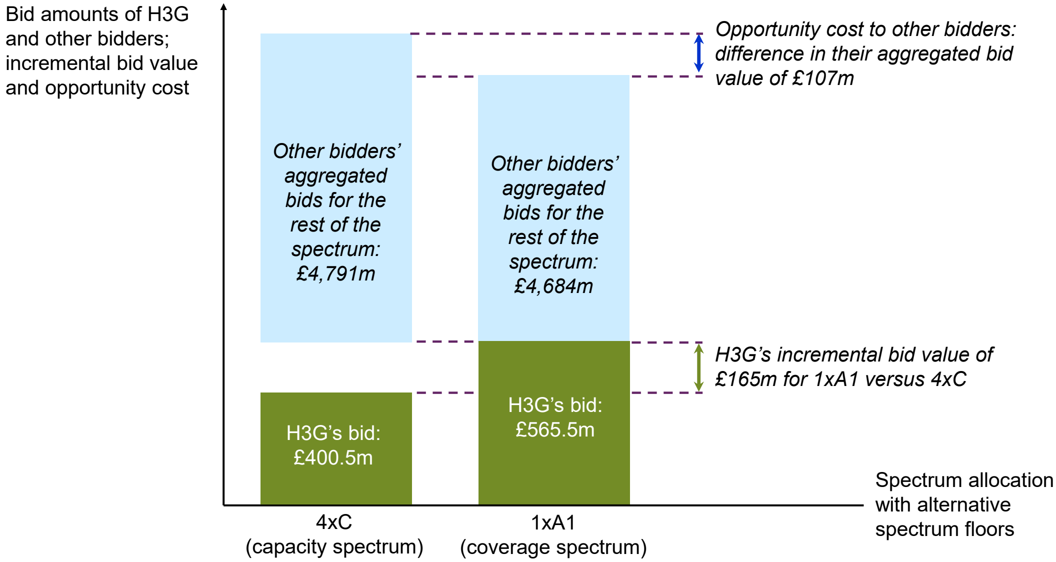
The auction design to implement the approach of spectrum floors meant that, in effect, the outcome was determined through linked sub-auctions within the overall auction:

- For reserved spectrum (4–16 per cent of the total spectrum auctioned) there could be competition between the two types of eligible bidder (H3G and new entrants), bidding for different spectrum floors.
- For unreserved spectrum other bidders (plus the eligible bidders beyond their spectrum floors) competed like they normally would for most of the spectrum in the auction.
- The choice of spectrum floor to be reserved then took account of both the benefits revealed by the bids of eligible bidders for reserved spectrum and the opportunity costs indicated by the bids of other companies.

As it turned out, only one eligible bidder, H3G, was willing to pay the reserve price for the spectrum floors, so there was no competition in the sub-auction for reserved spectrum. Ultimately, the reserved spectrum won by H3G was the smaller amount of low-frequency coverage spectrum, namely one 10 MHz lot of the 800 MHz band in category A1 (referred to as '1xA1') instead of the larger amount of higher-frequency capacity spectrum which was four 10 MHz lots of the 2.6 GHz band in category C ('4xC').[3] As shown in Figure 10.1, H3G preferred 1xA1 over the alternative spectrum floor of 4xC, and its bids indicated a benefit of £165 million – H3G's incremental bid value, the difference between its bids of £565.5 million for 1xA1 and £400.5 million for 4xC. This *benefit* exceeded the *opportunity cost* to other bidders of them being denied 1xA1 instead of 4xC – they would also have preferred to win 1xA1 instead of 4xC, but the strength of that preference expressed in their bids was £58 million less at only £107 million. (The reasoning to derive that opportunity cost was that, if the spectrum floor of 4xC were to be reserved for H3G in the first column of Figure 10.1, then the other floor of 1xA1 would be unreserved and available to other operators – their aggregated bid value for unreserved spectrum including 1xA1 was £4,791 million. Alternatively, if 1xA1 were the reserved spectrum for H3G in the second column, other bidders' aggregated bid value for unreserved spectrum including 4xC was £107 million lower at £4,684 million.)[4]

The use of spectrum floors in the 2013 auction serves to illustrate strengths and limitations of innovative market design. The regulator had no way outside auction bids to estimate reliably the benefits and opportunity costs of alternative spectrum floors. In the absence of better information, the

Figure 10.1. Choice of low-frequency spectrum (1xA1) as the winning spectrum floor in the UK's 2013 auction, because H3G's incremental bid value exceeded the opportunity cost to other operators



Source: Author from published bids in the 2013 auction.[5]

regulator was more likely to have chosen to reserve the lower-value capacity spectrum (4xC), if it had been forced to decide which spectrum to set aside before the auction. Based on the actual bids made, this would have been the wrong choice.

However, did the bids identify the most efficient outcome in this case? Some types of strategic bidding were foreseen and prevented by Ofcom's design choices. But H3G exploited a remaining gaming opportunity and guaranteed that it only paid the reserve price for its selected spectrum floor (by bidding an incremental value between the floors that matched the difference in their reserve prices of £225 million for 1xA1 and £60 million for 4xC). The firm's incentive to undertake this bid strategy was not entirely clear because the auction's pricing rule preserved a profit incentive to bid more straightforwardly. Also, H3G's approach was not driven by a simple budget constraint, because it ended up winning the much more expensive spectrum floor.

The bidding indicated a significant gap of £58 million between the incremental value to H3G for the higher-value coverage spectrum floor (1xA1) and the opportunity cost to other bidders. Compared to pre-auction expectations, it was surprising that the opportunity cost for this coverage spectrum was not higher, but it reflected a consistent pattern of bidding in the auction (especially EE's aggressive bidding at the margin for the higher-frequency capacity band). The question of the efficient choice of spectrum floor seems to turn on whether H3G's bid strategy substantially exaggerated its incremental intrinsic value. If H3G's true incremental intrinsic value was at least £107 million (the opportunity cost), an efficient choice was made in the auction. Only H3G held that information. However, if H3G's incremental intrinsic value was less than £107 million, it would have been more profitable for the firm to bid differently, reflecting that smaller differential value than the £165 million in its actual bids. The more that H3G's bid strategy departed from the difference in its intrinsic values, the larger a loss in profit it would have been risking. These incentives reduced the likelihood that H3G's incremental intrinsic value was more than 35 per cent less than in its actual bids and below the opportunity cost of £107 million (see Annex C1). Although not conclusive, the evidence is consistent with the auction mechanism of spectrum floors used by the UK regulator having made the economically efficient choice in the 2013 auction.

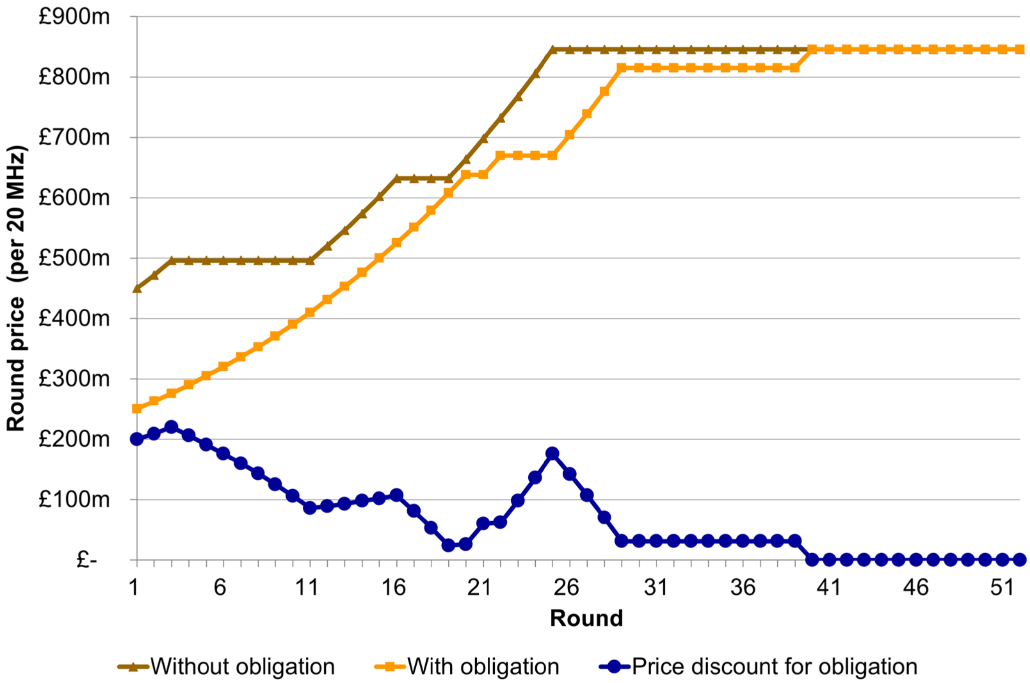
10.2 Extending mobile coverage: eliciting better information on costs

Another potential source of regulatory failure is misjudging the balance between costs and benefits of coverage obligations, which provide a challenging arena for impact assessments. The benefits of extending mobile coverage are not amenable to simple quantification and require significant policy judgement about the relevant broader social or public value. The costs to operators to expand their network coverage can be estimated by using network cost modelling. However, one reason for a potentially large error margin in any cost estimate is that it relates to a network which, by definition, has not yet been built, so requiring a range of assumptions to be made. Also, there is asymmetric information between the operators and the regulator. The operators would be the ones building the extended network, so they have better information about their costs. But their self-interest means they may not have an incentive to provide the regulator with unbiased cost estimates. Even without seeking to deliberately mislead the regulator (which can happen), operators are inclined to take a conservatively high view of the costs.

The price-setting function of auctions can illuminate the costs (but not usually the benefits) through pricing the coverage obligations. This was vividly seen in the UK's 2013 auction when the winning bidder, Telefónica, made the same bid for spectrum with and without the obligation (which was pre-attached to one of five lots in the low-frequency band, 800 MHz). These bids expressed a net cost of the obligation to Telefónica of zero, compared to Ofcom's deliberately conservative pre-auction estimate of £200 million, which in turn took account of pre-auction submissions from operators.[6] The contrast is illustrated by the evolution of prices in the clock stage shown in Figure 10.2. The blue line shows the price discount for the coverage obligation in each clock round. The discount is derived as the difference between the price for the same amount of 800 MHz spectrum without the obligation (the brown price line) and with the obligation (the orange line). The discount started in the first round at £200 million, the difference in the reserve prices chosen by Ofcom to reflect its pre-auction estimate of the cost of the obligation. By the end of the clock stage the discount had fallen to zero. An auction forces operators to put their money where their mouth is. In this way, it can reveal valuable market information that highlights the extent of regulatory failure in cost estimates.

Taking this one step further, innovation in design can harness the auction to contribute to some other difficult decisions which are prone to regulatory failure, such as the number and level of coverage obligations. Market information derived from auction bids can be used to conduct parts of the cost-benefit analysis within the auction itself. This approach draws on the insight that including coverage obligations in spectrum auctions makes them double-sided, with two logically distinct functions. The auction includes the *procurement* of coverage extension for public value, where the government pays operators to expand their network coverage. It also includes the *sale* of spectrum licences for economic efficiency, where the operators pay the government for rights to use valuable spectrum. The traditional approach is to link the two functions by pre-attaching a defined coverage obligation to specific spectrum in the auction, as in the UK in 2013. This method can work well, but it also has weaknesses because it mixes the two distinct functions when deciding the winner of the spectrum lots

Figure 10.2. Clock prices in the UK's 2013 auction for 800 MHz spectrum with and without the coverage obligation



Source: Author from published bids in the 2013 auction.[7]

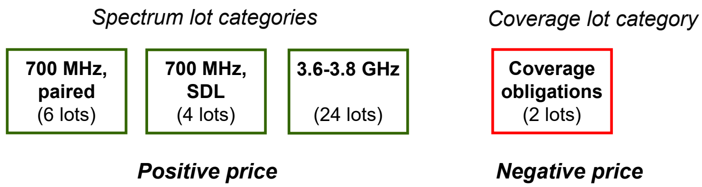
that have pre-attached coverage obligations – the winning operator may bid the highest either because it has the lowest cost of expanding its network to meet the coverage obligation, or because it has the highest value for the spectrum attached to the obligation.

There are methods that can decouple obligations from spectrum, so that the logical distinction between the functions is also reflected in the structure of the auction.[8] Direct procurement outside the spectrum auction is, of course, one way to separate the expansion of coverage from the allocation of spectrum, for instance through procurement auctions such as the USA's rural broadband auctions.[9] The approach of holding separate spectrum and procurement auctions has three types of advantages:

- Efficient spectrum allocation: The spectrum can be allocated more efficiently, to the operator with the highest value (auction efficiency), regardless of the operators' relative costs of meeting the obligation.
- Lowest-cost operator: The obligation can be awarded to the lowest-cost provider of extended coverage (productive efficiency), regardless of the operators' relative values for spectrum.
- Better-informed judgement about the balance of costs and benefits: By eliciting improved information about the costs of the obligation, more informed public policy decisions can be made.

Some of these advantages can also be obtained when there are coverage obligations in the auction through decoupling the functions of procurement and spectrum allocation. Two examples of partial decoupling are the 2018 proposals in the UK, and Austria's 2020 auction.

Figure 10.3. Proposed lot structure in 2018 with unbundled coverage obligations



Source: Author from Ofcom (2018b).

2018 proposals in the UK: cost-benefit analysis within the auction

Ofcom made proposals for coverage obligations in 2018 (as noted in Section 5.3). They were not implemented, because the 2020 agreement between the government and the operators provided for expanded mobile coverage, so that the obligations were not needed and taken out of the auction held in 2021. However, the way that the regulator proposed to integrate the obligations into the auction design demonstrates some of the possibilities from harnessing auctions. The approach is illustrated in Figure 10.3, showing the proposed lot structure in the CCA design, including separate lot categories for spectrum (shown in green) and for coverage obligations (in red).

The two different types of lot mirror the two functions of the auction. As usual, the spectrum lots have positive prices. Operators have to pay a price at least as high as the reserve price (the minimum acceptable sale price) to acquire the spectrum in three bands: 700 MHz paired, 700 MHz SDL, and 3.6–3.8 GHz. The second type of lot is the two decoupled (or unbundled) coverage obligations. If there is a cost associated with meeting coverage obligations, operators have to be compensated to take them on, so that the coverage lots have a negative price – a subsidy, or discount on the price of spectrum that the operator also wins. This discount provides an incentive to attract bids for the obligations, with the regulator setting the negative reserve prices (the maximum discount). Competition in the auction affects the price of both types of lot. Excess demand for a lot category leads to the price being raised. For spectrum this means a higher price for the relevant spectrum band. For coverage obligations, raising the price means a lower negative price, or a smaller discount. The unbundling of the coverage obligations allows bidders to select the spectrum they want to bid for alongside a coverage obligation, thereby mitigating the regulatory failure of the regulator choosing the wrong spectrum to pre-attach to obligations. Unbundling also removes the risk of unsold spectrum from the coverage obligations being too onerous. Operators can bid for spectrum that they value, either with or without bidding for coverage obligations.

In this novel design the spectrum and coverage obligations are awarded simultaneously, allowing the auction to perform a role to balance the benefits and costs of the obligations. The benefit side of the equation is performed by the maximum discount, if it is set by the regulator to reflect the benefits (public value) from an obligation expanding mobile coverage. On this basis the UK regulator indicated in its 2018 proposals a maximum discount in a range of £300–400 million.[10] The cost side of the equation is derived from auction bids, as the difference in total bid value with and without an obligation. The coverage obligation cost in the cost-benefit analysis is then endogenous to the auction, reflecting two cost categories. There is a network cost of meeting the obligation, the cost an operator expects to incur by building out its network to achieve the required coverage extension (net of revenues it expects to receive). In addition, there can be an opportunity cost from a change in the allocation of spectrum due to the coverage obligations, e.g. an operator winning more spectrum because of leveraging its lower costs of meeting the obligation (instead of the allocation just being determined by operators' values for that spectrum). A change in allocation can occur if there is incomplete decoupling of spectrum allocation and coverage procurement in the auction – in the UK, such partial decoupling arose from legal constraints.[11] The ability to identify the opportunity cost of a change in spectrum allocation exploits the richness of information and flexibility in the CCA format, as explained in the worked example in Annex C2.[12]

With the maximum discount set by the regulator to reflect policy judgement about the scale of coverage benefits and operators' bids revealing better-quality information about coverage costs, the cost-benefit-analysis role of the auction is twofold. The obligations can only be awarded if the discount is large enough to attract bids, meaning that an operator considers the benefits in the maximum discount are larger than its network costs of meeting the obligation. In addition, an obligation is awarded by the regulator only when the benefits represented by the maximum discount are at least as large as the costs reflected in auction bids, including the opportunity costs.

In this way the number of obligations procured is decided on the basis of the cost-benefit analysis of policy alternatives conducted within the auction (with the benefit side of the equation determined by the regulator in advance). Although not included in the regulator's 2018 proposals, the same principles could be applied to improve the choice of level of obligation – for example, whether the obligation should be for 90 per cent landmass coverage (as proposed by the regulator) or higher at 92 or 95 per cent. Optional add-ons to the basic 90 per cent obligation of +2 or +5 per cent could be offered at additional maximum discounts, reflecting the regulator's judgement of incremental coverage benefits. As for determining the number of obligations, the selected level of obligation would reflect the cost-benefit analysis within the auction. An add-on would only be awarded if it attracted bids and if the total costs, including any opportunity costs, did not exceed the benefits in the additional maximum discount.

The auction design therefore enables useful information about costs to be elicited from operators, allowing more informed decisions about coverage extension. There is a risk that strategic bidding could distort this information. However, sound auction design choices can mitigate strategic incentives (although not usually eliminate them). This means that market information from auctions can be better quality than pre-auction regulatory estimates 'in the dark'. The potential advantage is illustrated by the stark difference between the market information from the UK's 2013 auction, that the cost of the coverage obligation to the winning operator was zero, compared to the regulator's pre-auction estimate of £200 million. For the novel design in the 2018 proposals, implementation of the auction approach also requires the regulator to estimate the benefits of the obligation. That task is far from easy, but it can be done as indicated in 2018. Another way for public policy decision-makers to think about benefits is highlighted by the break-even cost-benefit question. How large would the costs have to be before, on balance, the obligation becomes disproportionate?

Austria's 2020 auction: granular coverage obligations

The 2020 spectrum auction in Austria included three bands – 700 MHz, 1500 MHz, and 2.1 GHz – and a range of coverage obligations.[13] It adopted a mixed model for the coverage obligations. Some were pre-attached to 700 MHz spectrum lots. Others were decoupled in a subsequent procurement stage, when operators could obtain a discount on the spectrum they had won in the previous stage. The product design for the obligations involved a large number of granular requirements, specified for 2,100 underserved municipalities. In all, 900 of the granular obligations were pre-attached to spectrum lots. Obligations for the remaining 1,200 municipalities were offered in the procurement stage. The granular obligations in this design offered a number of advantages of flexibility, especially in the procurement stage, in a trade-off against the increased complexity. Obligations could be taken on by the operator best able to supply each municipality at lowest cost. Operators could assess their costs, and decide which obligations to bid for in small increments of municipalities. The auction rules also provided for subsequent swaps of granular obligations between operators, using an exchange (web portal) set up by the regulator acting as a clearinghouse, to assist in fine-tuning the efficiency of the obligations' allocation.

A large proportion (81 per cent) of the coverage obligations for municipalities were taken up by operators (about 1,700 out of 2,100). The obligations were only awarded if the reserve price restrictions were met, which were set by reference to an estimate of coverage costs, not benefits.[14] As such, the reserve prices were performing more of a check on cost efficiency and a limit on the budget of available funding, rather than a cost-benefit function as in Ofcom's 2018 proposals in the UK.

Conclusions

The standard approach to coverage obligations is pre-attaching them to specified spectrum blocks. The examples from the simultaneous approach in the UK's 2018 proposals and the sequential stages for granular obligations in Austria's 2020 auction highlight that much more can be done through innovations in auction design to improve the procurement of increased mobile coverage and balance it with efficient allocation of spectrum. A similar point about the scope for innovative design is demonstrated in Section 10.1 on using the UK's 2013 auction to choose the spectrum to be reserved between alternatives to promote downstream competition. The wider lesson is that talk is cheap, whereas auctions bids are binding commitments. In the right circumstances, this power of well-designed auctions can be harnessed to incentivise the provision of market information to make better-informed public policy choices, thereby mitigating risks of regulatory failure and enhancing decisions about cost-benefit trade-offs. The auctions for coverage obligations illuminated the cost side of the equation, whereas in the example of spectrum floors, auction bids provided information on both the benefits and costs of policy alternatives.

Notes

1 Kwerel et al. (2017, p.467).

2 Specifically, the choice of spectrum floors for H3G was either 10 MHz at 800 MHz, or 40 MHz at 2.6 GHz; and for a new entrant either 30 MHz at 800 MHz, or 40 MHz across both the 800 MHz and 2.6 GHz bands (20 MHz in each).

3 In practice, the determining bids were made in the supplementary bids round. For further explanation of the bidding, see Myers (2013).

4 Figure B1.8 in Annex B1 also shows further detail of each operator's specific winning and alternative packages and their associated bid amounts for H3G to win 1xA1 compared to 4xC as the reserved spectrum.

5 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.

[6] In fact, Telefónica made a slightly higher bid by £1,000 for spectrum with the obligation. Its winning bid was £1,219.003 million for 20 MHz in the 800 MHz band including the obligation, and it bid £1,219.002 million for the same amount of 800 MHz spectrum without the obligation. The auction price that Telefónica paid was based on the second-price rule, reflecting the highest losing bid for the obligation by Vodafone, and included a discount of £31 million compared to the price without the obligation – see Ofcom (2015, paragraph 2.59a)).

[7] 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.

[8] Ihle and Taylor (2020).

[9] FCC 'Rural Broadband Auctions', https://perma.cc/L427-GG5F.

[10] For various complications and the derivation of the proposed range for the maximum discount, see Ofcom (2018b, annex 13).

[11] The incomplete decoupling was caused by the UK regulator's statutory powers not allowing it to make a net outpayment to any auction bidder. This restriction limited the largest size of any bidder's discount to the price paid for the spectrum that it acquired in the auction, which Ofcom called the 'positive price constraint', because the overall price paid in the auction by any bidder, net of discounts for a coverage obligation, was not legally permitted to be negative. The positive price constraint could lead a bidder for a coverage obligation to artificially increase the amount of spectrum in its package in order to increase its effective discount. In other countries where the regulator has powers to make net outpayments to a bidder from an auction, the unbundling of the coverage obligations could fully decouple procurement of coverage extension from spectrum allocation. The cost-benefit issue would then just be about attracting bids at a maximum discount that is set by reference to the expected benefits of the obligation.

[12] In addition, a *simultaneous* auction of spectrum and coverage obligations (as in the 2018 proposals) can derive this opportunity cost of different spectrum allocations depending on whether the coverage obligation is awarded. However, it would not be revealed in a *sequential* award of spectrum and then obligations.

[13] RTR 'Multi-band auction 700/1500/2100 MHz (2020)', https://perma.cc/ZCY2-DWWT.

[14] There was a maximum total discount for the procurement stage that the bidders could obtain between them, and also a maximum discount for a certain number of municipalities.

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Note: 🔓 means an open access publication.

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11. Auction bidding and outcomes

Summary

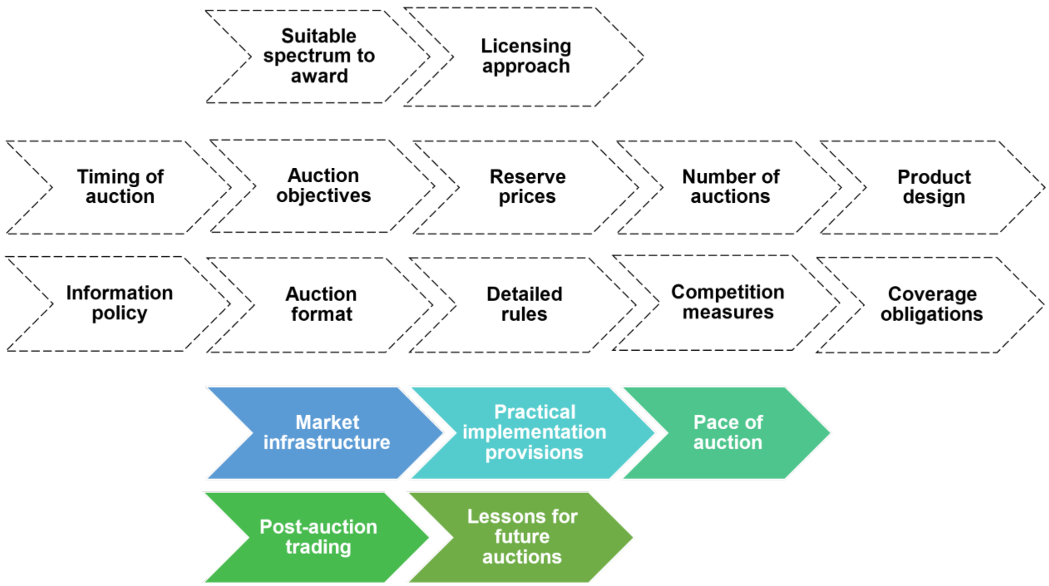
- Over 20 years of auctions, the UK regulator's process of learning from experiences and adapting its design decisions depending on the circumstances helped to avoid serious mistakes, and the auctions were largely successful in promoting economic efficiency.
- Strategic bidding that could not be deterred by the design choices had more impact on auction prices than on distorting the efficient allocation of spectrum (such as high prices from apparent overbidding in 2000, and low prices from tacitly collusive market division in 2021).
- The surprises compared to pre-auction expectations illustrate the benefits of using auctions to draw on bidders' decentralised information, compared to the regulatory failure risks inherent in administrative allocation decisions.
- One of the range of practical implementation decisions is how the regulator influences the pace of the auction through the schedule of rounds and the size of the price increment between the rounds of bidding. The regulator trades off enough granularity and time for bidders to make decisions for auction efficiency against longer auctions which could reduce output efficiency by delaying the benefits to consumers.
- Trading of spectrum licences can be a supplement or partial alternative to auctions, as in 2021. However, the multilateral process in auctions with a clearinghouse can generally achieve increased economic efficiency.

Spectrum auctions are often unpredictable, and the surprises can be pleasant with attractive results, or they can take the form of undesirable processes, bidding behaviours, or outcomes. The first section reviews the UK experience to draw out valuable lessons for future auctions. The second section then turns to the implementation issues highlighted in the penultimate row of Figure 11.1, exploring in particular how the regulator can manage the pace of the auction. The final section considers how the

How to cite this book chapter:

Myers, Geoffrey (2023) *Spectrum Auctions: Designing markets to benefit the public, industry and the economy*, London: LSE Press, pp. 197–213. https://doi.org/10.31389/lsepress.spa.k. License: CC BY-NC-ND 4.0

Figure 11.1. Auction decisions covered in Chapter 11



Source: Author.

ownership of licences can change as a result of post-auction trading – sales or swaps – of spectrum between mobile providers, which can provide a helpful supplement to the allocation process in the auction itself.

11.1 Learning lessons from UK auctions

Anyone who has experienced the emotions of being inside the auction room (as I was for the UK's 2013, 2018, and 2021 awards) will appreciate the difficulties of trying to forecast the pattern of bidding by firms, and how the hopes for favourable outcomes can be upheld or dashed by the way that operators choose to bid. The regulator sets the rules and operates the auction, but cannot control how bidders behave, however thorough its planning. This creates considerable potential for surprises to occur and for strategic bidding by companies seeking to exploit loopholes in the auction design. Operators and the regulator can also make mistakes in their bid strategies or design choices. Previous chapters have utilised aspects of the UK's high-stakes auctions as examples to illustrate many of the regulator's design options and decisions, such as setting reserve prices in Chapter 7, choosing the auction format in Chapter 8, and deciding competition measures in Chapter 9. Here I compare how the bidding outcomes matched with the regulator's objectives and expectations, and show how valuable lessons for future auctions can be gleaned from the varied experiences. Annex A provides more detail and evidence to support this commentary, and sets out the full story of each auction.

The revenues generated by auctions are usually prominently reported, and the large disparities between the UK auctions are shown in the first row of Figure 11.2, ranging from £22.5 billion in the 'biggest auction ever' in 2000 to only £1.4 billion in 2018 and 2021. As we shall see, mistakes and

Figure 11.2. Revenue outcomes and rivalry in four high-stakes UK auctions

Issue	3G auction in 2000, 'biggest auction ever'	4G auction in 2013, 'surprises and complications'	PSSR auction in 2018, 'widely seen as successful'	5G auction in 2021, 'short and sweet?'
Revenue	There were very high prices and revenue of £22.5 billion, compared to reserve prices of £0.5 billion.	The revenue of £2.4 billion was well above reserve prices of £1.4 billion.	The prices and revenue of £1.4 billion were much higher than the reserve prices of £0.07 billion, and within an expected range for a competitive auction.	The prices and revenue of £1.4 billion were above reserve prices of £1.1 billion, but still looked low: 45% lower than in 2018 for 5G capacity spectrum; and relatively low by international standards for 5G coverage spectrum.
Rivalry in the auction	There were 13 bidders for 5 licences, contested over 150 rounds of bidding.	The 7 bidders competed, with 5 winners after 52 clock rounds and the supplementary bids in the CCA design.	All 4 incumbents won spectrum after 67 rounds of bidding, and a potential entrant was outbid.	The 4 incumbents were the only bidders over just 4 rounds of bidding for the 5G capacity band, and 11 rounds for the coverage spectrum.

Source: Author from Ofcom auction documents[1] and National Audit Office (2001).
PSSR: Public Sector Spectrum Release.

strategic bidding contributed to the differences, and another factor was the strength of competition in the auction between bidders as indicated in the second row – very strong rivalry in 2000 between 13 firms over 150 bidding rounds, but weak in 2021 between just four operators over 11 rounds. In all cases the regulator successfully sold all the spectrum on offer, partly by consistently setting reserve prices below the spectrum's market value.

However, the revenue raised by an auction does not provide the best basis to judge whether it has been successful, because the outcomes for economic efficiency are usually far more important (see Section 7.2). When assessed on the criteria of auction and output efficiency – see Figure 11.3 – the 2021 auction looks 'short and sweet' despite the low revenue it generated. These criteria also explain why the 2018 auction was 'widely seen as successful', whereas the outcomes of the 2013 auction were more mixed and inconclusive for economic efficiency.

Strategic bidding can come in many forms. It seems to be a phenomenon that each bidding firm claims it would not dream of doing, while often alleging that it is rife in its rivals' bids. Distinguishing strategic from straightforward bidding in practice is sometimes clear, but can often be difficult without knowing the underlying spectrum valuations which are private to the bidders. Many observed bid patterns are potentially consistent with both. There were instances of probable strategic bidding in all four UK auctions as set out in Figure 11.4, but their main impact seemed to be on prices rather than

Figure 11.3. Economic efficiency in UK auctions

3G auction in 2000, 'biggest auction ever'	4G auction in 2013, 'surprises and complications'	PSSR auction in 2018, 'widely seen as successful'	5G auction in 2021, 'short and sweet?'
It is likely that the spectrum was allocated to the highest-value bidders. The set-aside for a new entrant supported strong downstream competition (see Chapter 9). It remains controversial as to whether or not high auction prices delayed operators' 3G investments. But there was no significant evidence of higher consumer prices (see Section 7.2).	The extent of auction efficiency is unclear (e.g. package bids allowed firms to express synergies in their spectrum values, but some bidders may have been adversely affected by the difficulties of bidding with budget constraints – see Section 8.2). Flexible spectrum reservation (floors) supported downstream competition between four credible operators. However, the degree of spectrum asymmetry between operators increased (see Chapter 9).	The outcome looked efficient both for spectrum allocation and to support downstream competition in 4G and 5G services.	The spectrum allocation seemed efficient, and the outcome was also desirable for downstream competition between operators in both coverage and capacity.

Source: Author.

Figure 11.4. Strategic bidding in UK auctions

3G auction in 2000, 'biggest auction ever'	4G auction in 2013, 'surprises and complications'	PSSR auction in 2018, 'widely seen as successful'	5G auction in 2021, 'short and sweet?'
Price driving by BT may have raised the price paid by Vodafone.	Some strategic bids were made, but it is unclear that they affected the outcome.	The possible price driving by H3G in the 4G band may have caused an increase of 50% in the price paid by Telefónica. However, the evidence could also be consistent with straightforward bidding.	There was clear evidence that bidders successfully engaged in market division (tacit collusion) in the 5G capacity band, leading to the low prices paid by EE, Telefónica, and Vodafone.

Source: Author.

the efficiency of the spectrum allocation. Price driving may have *increased* the prices paid by Vodafone for 3G spectrum (2.1 GHz) in 2000 and by Telefónica for 4G spectrum (2.3 GHz) in 2018. And tacitly collusive market division *reduced* the prices paid by all four incumbents for the 5G capacity band (3.6–3.8 GHz) in 2021.

Figure 11.5. Surprise outcomes in UK auctions

3G auction in 2000, 'biggest auction ever'	4G auction in 2013, 'surprises and complications'	PSSR auction in 2018, 'widely seen as successful'	5G auction in 2021, 'short and sweet?'
Very strong competition in the auction and high prices led to the auction revenue far exceeding the pre-auction forecast of only £1–3 billion.	The revenue of £2.4 billion was below the pre-auction revenue forecast of £3.5 billion by the Office of Budget Responsibility (see Section 5.1). The spectrum allocation, including very different amounts won by operators, led to a distribution at the limits of asymmetry set by the safeguard spectrum caps (see Figure 2.5). BT outbid some incumbents to win a material amount of 4G capacity spectrum. The reserved spectrum (floor) decided by auction bidding was the higher-value coverage spectrum (see Section 10.1).	All four incumbents won spectrum which allowed them to launch 5G services (instead of fewer firms winning larger blocks).	Although a risk of market division was evident beforehand, the rivalry in the auction was very weak for the 5G capacity spectrum and limited for the coverage band.

Source: Author.

The desirability of perceived 'surprises' can depend on the eye of the beholder. The intensity of competition in the 2000 auction was reflected in the surprisingly high prices and revenue, many times larger than the official pre-auction forecast shown in Figure 11.5. By contrast, revenue fell well short of the forecast in 2013. The details of the spectrum allocation in 2013 also included other surprises, such as the extent of spectrum asymmetry it caused and the unexpected winners of some of the spectrum. The element of surprise in the allocation in 2018 was desirable for 5G competition between all four operators. These surprises generally indicate the difficulties for the regulator in making accurate judgements about efficient spectrum allocations in administrative processes without the benefit of decentralised market information from operators' auction bids.

Before the 2021 auction the regulator had understood the risk of undesired gaming of the auction by operators via market division in the 5G capacity band, so it was less of a surprise than it might seem to the outside observer. Ofcom chose nevertheless to deploy the SMRA format despite its vulnerability to market division, because the spectrum allocation of an equal split between three operators was still plausibly efficient (see Table 11.3), and it did not have revenue-raising as one of its auction objectives.

The major mistake of overbidding by firms participating in the 2000 auction now seems clear with the benefit of hindsight. It may have arisen from excessive optimism at the time about the commercial attractiveness of 3G services, exacerbated by the pressure of stock market expectations that failing to win a 3G licence could 'ring the death knell' for an operator and force it to exit the mobile market. Figure 11.6 shows that the 2013 auction also saw a few bids that seem like mistakes, although they did not have anything like as large an impact as in 2000.

Figure 11.6. Mistakes by operators and the regulator in UK auctions

3G auction in 2000, 'biggest auction ever'	4G auction in 2013, 'surprises and complications'	PSSR auction in 2018, 'widely seen as successful'	5G auction in 2021, 'short and sweet?'
Overbidding by firms may have been caused by a winner's curse and managerial overconfidence about the commercial prospects of 3G services.	Some firms made unusual bids, such as instances of bids by BT with negative incremental values for more spectrum. Detailed design decisions by the regulator contributed to only limited price discovery in the auction (e.g. activity rules and eligibility points – see Section 8.4 and Annex B3). Not all of the 'bells and whistles' in the complex CCA design turned out to be desirable.	No clear mistakes by the bidders or the regulator.	More revenue could likely have been generated by higher reserve prices for 5G capacity spectrum – however, revenue-raising was not an auction objective. There was potential for a more effective approach to defragmentation of 5G spectrum (see Section 11.3).

Source: Author.

While the regulator's design decisions had some weaknesses, it avoided major mistakes (especially when compared to some flawed auctions elsewhere, which required rule changes during the auctions themselves to enable them to end, as in Finland, Poland, and Portugal). Some commentators could view the design decision for the 2021 auction as a mistake, where the companies outsmarted the regulator. However, as explained in the context of strategic bidding, this criticism would be greatly exaggerated, and the true position is that the bidding and outcome derived much more from differences in objectives between the operators (low prices) and the regulator (economic efficiency, but not revenue-raising).

Valuable lessons for future auctions have been learned from the range of experiences, as set out in Figure 11.7. Operators learned hard lessons about overbidding which they have generally avoided repeating. The regulator similarly learned from admittedly less consequential problems, such as including one too many complications in the design for the 2013 auction. Lessons have also been taken from successes, such as the design choices which facilitated an attractive bidding process and outcome in 2018, as well as the lower-profile achievements from successfully using a second-price rule in assignment stages in 2013, 2018, and 2021 (see Annex A). Another set of lessons relates to benefits from developments in thinking, such as adjusting the balance between simplicity and flexibility in moving from pre-packaged licences in 2000 to more granular, generic lots for later auctions (see Section 7.5), and adapting to changing market conditions through a horses-for-courses approach to fit the auction format to the specific circumstances (see Section 8.5). Finally, the combination in 2021 of a desirable spectrum allocation but tacitly collusive bidding and low prices highlights the importance of understanding the auction's objectives, such as the relative importance of economic efficiency and revenue-raising, when judging the most appropriate design decisions and when assessing its success or failure.

Figure 11.7. Learning from UK auctions

3G auction in 2000, 'biggest auction ever'	4G auction in 2013, 'surprises and complications'	PSSR auction in 2018, 'widely seen as successful'	5G auction in 2021, 'short and sweet?'
Operators learned to avoid overbidding in future auctions in the UK and elsewhere. The regulator moved to more granular, generic lots in future auctions.	The 'heavy machinery' of the CCA format and other complications should only be chosen by the regulator when they are really needed. The second-price rule was effective and far less contentious in the assignment stage to award specific frequencies, than in the main bidding (principal) stage which determined the winners and their spectrum amounts.	The auction design which was successful for both the bidders and the regulator could be deployed again, if future conditions were sufficiently similar.	Despite the regulator using the same essential auction design in 2021 as in 2018, the bidders behaved very differently with far weaker rivalry and much more strategic bidding. Achieving good outcomes for economic efficiency outweighed the undesirable aspects of weak rivalry, tacit collusion, and low prices in the auction.

Source: Author.

11.2 Practical implementation decisions, including the pace of the auction

All auction participants – bidders and the regulator – make a range of implementation decisions in order to take part in the auction. The regulator can influence the pace of the auction, striking a balance between usually modest gains in auction efficiency and risks to output efficiency from delay.

Overview of implementation provisions, including deposits

The regulator provides market infrastructure like the electronic auction system, and provisions for security and confidentiality of information. Before the auction, bidders may be given access to the auction system for training purposes (and for auctions using the more complicated CCA format, the winner and price determination software can be made available, as well as additional arrangements for auction verification – see Section 7.6). The regulator also specifies the application process to participate in the auction, including minimum requirements on each bidder such as being a 'fit and proper person'.

Bidders have practicalities of their own governance structures to check and approve bid strategies before or during the auction. In addition, each participant has to implement the infrastructure of its auction room, including security of physical access and information technology. Preparations for the UK's 2021 auction were affected by Covid-19, and participants may have varied their usual arrangements as a consequence. Some perhaps used virtual (online) auction rooms, given the general resilience of broadband infrastructure even during the pandemic and the complications of social distancing requirements in physical rooms.

For bidders to participate in an auction, they will also need to ensure that financial resources are available to fit their strategy, such as making deposits and paying prices at the end of the auction. Different countries have used a range of approaches for the financial deposit requirements imposed on bidders during the auction. The UK adopted a relatively stringent approach, which is more onerous for bidders. But it helped to ensure that operators were genuinely committed to their bids, and so reduced risks of default. Initial auction deposits were decided by the firms depending on the number of eligibility points they wanted to have for the first round of bidding. For auctions after 2000, bidders could be asked to make top-up deposits during the principal stage up to the amount of their highest exposure so far (such as the bid value of their standing high bids).[2] As an example, top-up deposits were required on four of the days during the two weeks of bidding in the 2018 auction. At the end of the principal stage, bidders were required to ensure that they had on deposit the amount of their principal stage price, and to increase it after bidding in the assignment stage so as to cover their highest assignment stage bids.

Granularity and time for bidder decisions

Auctions for online advertising take milliseconds using automated bidding, but spectrum auctions last for days, weeks, or months. One feature of a successful market from Section 3.1 not fully analysed so far is 'congestion', in this context relating to the granularity of, and time for, bid decisions. With hundreds of millions or billions of pounds at stake, choices about the pace of the auction can support or adversely affect the success of the market. In many rounds, bidders' decisions are routine or pre-planned, but now and then they can have important bids to think through. Operators might be faced with too much congestion, such as insufficient time to make carefully judged bid decisions that need to be cleared through their internal governance. Conversely, auctions can be too slow to resolve and delay putting the spectrum into productive use to deliver new services or quality improvements to consumers.

The pace of the auction is strongly affected by bidders, such as the extent of bidding that made the UK's 2000 auction last much longer than expected, or the weak competition that curtailed the 2021 auction. However, the regulator can affect the pace through its choices. One decision that can lengthen the auction is low reserve prices (see Section 7.3). Another is using frequency-specific instead of generic lots in the product design (see Section 7.4). The auction format can also affect auction duration – for example, SMRAs are slower than simple clock auctions which do not involve standing high bids to be displaced (see Section 8.1). Other important implementation decisions for the regulator are the bid or price increments – the amount by which bids or price increase between bidding rounds – and the schedule of rounds per day.

The choice of bid increment highlights a trade-off between auction efficiency and output efficiency. Discussions of bid increments in the existing literature have tended either to focus on revenue, or a trade-off between auction efficiency and incremental participation costs to bidders and the auctioneer (such as the opportunity cost of time of the bid team, their advisers, and senior executives involved in governance decisions).[3] Such costs are relevant, but the analysis here emphasises the impact on output efficiency of delay in access to the spectrum, which can be especially relevant in particular cases. For example, some operators winning 2.3 GHz and 700 MHz paired spectrum in the UK's 2018 and 2021 auctions started to use it in their networks within a day of the licences being granted (Telefónica and EE).[4]

An example of a long auction adversely affecting output efficiency was Portugal's 2021 auction, which awarded spectrum for 5G services and included set-aside spectrum for new entrants. The pace of the auction was agonisingly slow, finally ending after more than nine months and a record 1,727 rounds of bidding over 201 days.[5] The slow pace derived from the unfortunate confluence of various design features. Bidding started from low reserve prices. From a menu of options, bidders could choose their bid increments as small as one per cent. Granular lots attracted separate bids in an SMRA format, instead of the faster pace with generic lots or a simple clock auction. For example, the 5G capacity spectrum band included 30 lots of 10 MHz each in one group which were close substitutes. When there was not much excess demand, this meant it could take 30 rounds to increase the price by just one per cent on substitute spectrum, through displacing the standing high bidder at the previous price on each of the 30 lots in turn.[6] The incumbents also seemed to have an incentive to delay, because the new entrants would not receive their spectrum to compete against them in the downstream market until the end of the auction. The very lengthy auction delayed the time when Portuguese consumers benefitted from increased mobile competition, improved coverage, and 5G deployment. Portugal was the last country in the European Union (apart from Lithuania) to launch 5G services.[7]

The trade-off between auction and output efficiency for price increments

One side of the trade-off is how the risk of a loss in auction efficiency varies with the size of the price increment. The standing high bid mechanism in the SMRA means that bidders can face different prices in the same round. For example, when two operators are competing, the standing high bidder (S) placed its bids at the price in the previous round. To displace S, a non-standing high bidder (N) has to bid at the current round price, which is higher by the amount of the price increment. This leads to the possibility of an inefficient allocation, if bidder N has a higher value of the spectrum than S, but fails to win because the price increment is too large. The risk is that the price increment overshoots the market-clearing price — in effect, there is congestion because the decisions that the regulator asks bidders to make are insufficiently granular.

A useful approximation of the maximum expected allocative efficiency loss per lot is the price in the penultimate round multiplied by the square of the percentage price increment.[8] Taking the 700 MHz paired band in the UK's 2021 auction as an example, the penultimate round price was £140 million per 10 MHz lot and the percentage increment in the final round was 7.1 per cent. The approximation suggests a maximum expected loss in auction efficiency for the final lot of about 0.5 per cent of the price, or £0.7 million. Another example yielding a similar maximum expected loss is from the UK's 2000 auction—prices were very much higher but offset by a smaller percentage price increment. The penultimate price was £3,970.5 million and the price increment that led NTL Mobile to drop out to end the auction was 1.5 per cent, suggesting an approximate maximum expected efficiency loss of 0.0225 per cent, or just £0.9 million.

The approximation assists sensible regulatory judgements about the size of the price increment and how to vary it during the auction (while recognising that the underlying method has limitations). The examples illustrate that the expected loss in auction efficiency can be made rather small by choosing a suitable price increment later on when there is a greater risk of the auction ending. A common approach is to start with a larger price increment when there is plenty of excess demand, and reduce it in later rounds when excess demand falls. But the first example from the 2021 auction also shows that the expected loss can be small even with a sizeable percentage increment.

The other side of the trade-off is the economic welfare cost of a slower auction in participation costs for bidders and the regulator, and losses in output efficiency from delaying access to the spectrum. In some cases, these losses will be small, for instance the date of the auction may be comfortably in advance of deployment of the spectrum. Such circumstances suggest that a desirable trade-off is a sufficiently small increment to keep a lid on the potential loss in auction efficiency even if it prolongs the auction. However, given the approximation, the price increment does not need to be that small – for example, with a 5 per cent increment the maximum expected loss per lot is only 0.25 per cent of the price. Unless auction prices reach very high levels, this increment is unlikely to give rise to substantial concern. Moreover, there are cases when delay in the auction from an excessively small price increment causes losses to consumers, as in the example from Portugal. If so, a better balance is to maintain a sizeable price increment and allow the auction to proceed more quickly, such as avoiding small increments like 1 or 3 per cent. The marginal gain from improved auction efficiency is likely to be offset by the loss in output efficiency.

Another relevant attribute of the price increment is its predictability for bidders. Depending on their internal governance arrangements, operators may need to plan when to trigger financial arrangements to make top-up deposits, or to engage with their senior executives, for instance at threshold bid amounts. These considerations may depend more strongly on the absolute level of prices, but percentage price increments mean that the absolute size of the increment increases with the price level (unless the percentage increment falls sufficiently quickly). In addition, in the approximation the maximum expected loss in auction efficiency grows with the absolute level of prices, as well as the square of the percentage price increment. For the 700 MHz paired band in the UK's 2021 auction, the regulator set the price increment in absolute terms at £10m per lot throughout the auction, which provided maximum predictability (especially desirable during Covid-19 restrictions). There were also only modest risks of losses in auction efficiency. At the start of the auction, the absolute increment represented 10 per cent of the reserve price of £100 million. As the price increased over the rounds, the associated percentage increment correspondingly fell. According to the approximation, the implied expected loss in auction efficiency per lot was comfortably less than £1m throughout the auction, and it declined over the rounds (because the reduction in the percentage increment was fast enough to more than offset the increase in the price level). In the right circumstances, increments set in absolute monetary amounts can be an attractive approach.

The schedule of rounds per day affects the duration of the auction in addition to the choice of price increment. The range of acceptable number of rounds per day can be influenced by country circumstances, how experienced the bidders are, and the nature of their internal governance arrangements. The schedule can be varied through the auction, depending on the state of play. For instance, the UK's 2018 auction started at five rounds on the first bid day and then moved to seven rounds from day 2. Later in the auction the level of excess demand was lower, so that the auction progressed more slowly (because it took several rounds to displace all the standing high bids at the previous price). From round 47 the schedule was increased to nine rounds per day for the last few days.[9] Portugal's 2021 auction started at four rounds per day, and ultimately increased to twelve rounds per day (after day 120). Some auctions around the world have been run with many more rounds – for instance, Italy's 2011 auction lasted 469 rounds over 22 days, an average of more than twenty-one rounds per day.

The overall pace of the auction

The pace of the auction is affected by a range of levers that the regulator can pull, including reserve prices, lot structure, auction format, price increments, and round schedules. These interact and different combinations can allow the auction to proceed at a reasonable pace. For example, Italy's 2011 auction used small price increments and many rounds, but a large number of rounds per day. There is a regulatory failure risk of a bias towards the pace of the auction being too slow. Operators often prefer a slower and more granular auction which can assist their decisions on bid strategies. The nature of the regulatory process may also incline towards going along with the preference of the company wanting the slowest pace. These are usually entirely legitimate reasons. However, they leave out of the picture the interests of consumers, which may be under-represented in the debate, putting more onus on the regulator to fully reflect the consequences of the pace of the auction for output efficiency.

The overarching framework for decisions about the pace of the auction is a trade-off between *auction* efficiency and *output* efficiency, which very much depends on circumstances so that it is not too fast and not too slow. For auction efficiency, the pace of the auction affects the congestion faced by bidders, both the granularity of their decisions (such as size of the price increment) and the time they are given to make their choices (the schedule of rounds). For price increments, the approximation of maximum expected auction efficiency losses suggests that an increment of 5 per cent is unlikely to lead to a significant efficiency concern unless prices reach very high levels. Although smaller price increments, like 1 or 3 per cent further reduce the expected loss in auction efficiency, the gain is usually modest. There can be an important downside from a slow auction, delaying deployment and deferring consumer benefits from new, better-quality services or increased competition, such as for Portugal's 2021 auction.

11.3 Spectrum ownership changes outside auctions

Auctioned licences in the UK are tradeable, allowing for post-auction adjustments to take place between firms – for example if bidders have regrets, circumstances change unexpectedly over time, or auctions create new opportunities for substitutes or complements. Figure 11.8 shows that there have been few trades of mobile spectrum in the UK where one licensee sells spectrum to another. The small number may reflect barriers to trading, such as transactions costs, coordination failure between linked trades, strategic motivations, and bargaining problems (e.g. arising from market power, asymmetric information, and incentives to hold out). Trades are more common in some other jurisdictions with regional licensing such as the USA, perhaps reflecting greater trading opportunities. Other changes in mobile spectrum holdings in the UK have occurred through mergers between firms – for instance, H3G took over UK Broadband in 2017 and acquired 120 MHz of prime 5G spectrum in the 3.4–3.8 GHz band.

Spectrum defragmentation after the UK's 2021 auction

Mobile operators may decide to swap spectrum between themselves, rather than selling it. Events after the UK's 2021 auction fall into this slightly different category. The swaps took place because of some very specific issues about defragmentation of holdings in the wider 3.4–3.8 GHz band, the primary spectrum for early 5G deployment in Europe. Section 7.4 gave this wider band as an example of sequential awards – the lower part, 3.4–3.6 GHz, was awarded in 2018 and the upper part, 3.6–3.8 GHz, in the 2021 auction because they became available for mobile use at different times. After the 2021 auction, three of the mobile operators had separate blocks wide apart in each of these sub-bands. However, there were technical efficiency gains from defragmenting so that each operator held closer blocks ('proximity'), and potential for further gains from contiguous spectrum holdings.

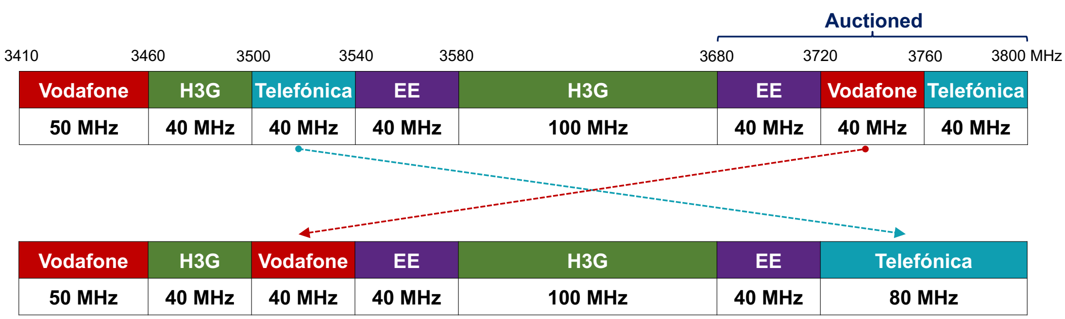
Figure 11.8. Sales of mobile spectrum licences in the UK through trades to operators

Spectrum and year	Description
1800 MHz in 2012	As a condition for approving the merger of Orange and T-Mobile in 2010 to establish EE, the competition authority imposed a spectrum divestment remedy.[10] EE sold 30 MHz to H3G in advance of the 2013 auction (otherwise the spectrum would have been included in that auction).
1.4 GHz (L Band) in 2015	Qualcomm originally won 40 MHz of this spectrum in a 2008 auction for just £8 million. At the time this band was not regarded as being mobile spectrum – the expected use was for mobile TV or digital radio. Qualcomm later re-purposed the spectrum for supplementary downlink (SDL) capacity in mobile networks. It traded 20 MHz each to H3G and Vodafone in 2015. Press reports suggested it earned £200m in revenue from the sales.[11] This episode highlights the distinction between fairness and economic efficiency, because it involved a large multinational company profiting from a public asset, but also resulted in improved efficiency of the spectrum allocation.
2.6 GHz unpaired in 2020	BT won this spectrum in the 2013 auction. Over time, after BT took over EE, it became more valuable for Telefónica which had much smaller holdings of capacity spectrum, leading to mutual gains from an efficiency-enhancing trade.

Source: Author.

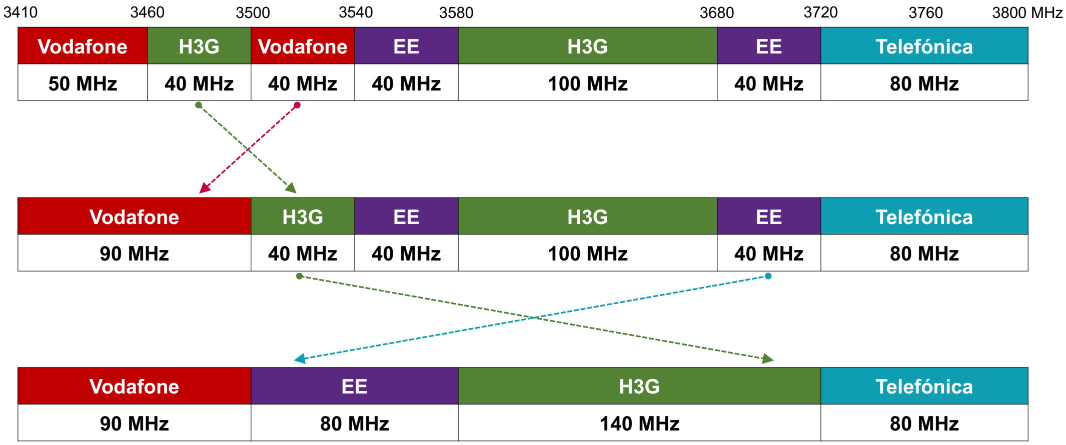
On the day that the 2021 auction ended, two operators (Telefónica and Vodafone) announced their agreement to swap spectrum and reduce fragmentation, a process that the assignment stage in the auction had been designed to facilitate (see Annex A5).[12] The effect of this trade is shown in Figure 11.9, changing the band plan from the immediate post-auction position in the top row to the post-trading situation in the bottom row. At the start, only H3G had 100 MHz of contiguous spectrum. After the swap Telefónica had 80 MHz of contiguous spectrum, and Vodafone's two blocks were much closer together so it could obtain the gains from sufficient spectrum proximity. EE's two blocks were unchanged but close enough for them to get these gains as well.

Figure 11.9. Post-auction spectrum swap between Telefónica and Vodafone in the wider 3.4–3.8 GHz band, achieving contiguity for Telefónica and proximity for Vodafone



Source: Author.

Figure 11.10. Possible further spectrum trades in the wider 3.4–3.8 GHz band to achieve full defragmentation



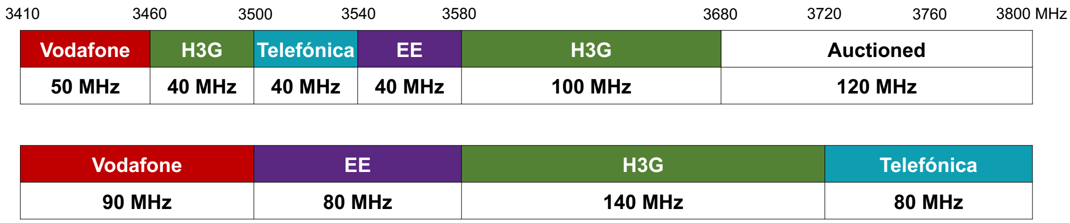
Source: Author.

There could be further gains in economic efficiency from possible further linked trades to lead to full defragmentation, first between H3G and Vodafone, and then between H3G and EE – Figure 11.10 illustrates that these two further swaps could bring all of EE's, H3G's, and Vodafone's separated blocks together to become contiguous. These trades would involve incremental costs for operators to relocate their frequencies to offset against the incremental benefits. Operators could reflect these effects in their trading negotiations. But the risks of a coordination failure or breakdown in bilateral negotiations could get in the way.[13] At time of writing, 18 months after the auction, the further trades and full defragmentation had not occurred.

An alternative approach would have been for the regulator to seek to achieve contiguous holdings for all operators within the 2021 auction itself, through a 'grand assignment stage' for full band reassignment of the wider 3.4–3.8 GHz band. The regulator could have required all holders of pre-existing 3.4–3.8 GHz spectrum to include it in the assignment stage, including both the 3.6–3.8 GHz spectrum won in the immediately preceding principal stage of the auction and operators' pre-existing holdings of 3.4–3.6 GHz spectrum. Bids made by operators could have reflected their preferences for different frequency locations, including avoiding the costs of relocating existing holdings to different frequencies. In principle, this was an attractive mechanism to achieve full defragmentation, deploying a different type of market than trading, a multilateral process with a clearinghouse. That can provide more coordination than bilateral negotiation for trades, especially where – as here – there were multiple linked trades. In a multilateral mechanism the transactions can occur simultaneously, whereas bilateral trading involved a sequential process with the benefits of some trades depending on subsequent swaps also occurring. An illustration of one of the possible outcomes from a grand assignment stage is shown in the bottom row of Figure 11.11 (which is the same as the bottom band plan in Figure 11.10), compared to the pre-auction position in the top row.

The illustration assumes that the same spectrum amounts would have been won in the prior principal stage of the 2021 auction, which is not certain. A further benefit of a grand assignment stage could have been to the competitiveness of principal stage bidding. Without a grand assignment stage, and

Figure 11.11. Illustration of a possible outcome with an alternative approach to achieve full defragmentation via a grand assignment stage in the auction



Source: Author.

relying on post-auction trades for defragmentation, operators knew that acquiring exactly 40 MHz in the 3.6–3.8 GHz band, no more and no less, was important to allow the post-auction swaps shown in Figure 11.9 or Figure 11.10. This is why the allocation of 40/40/40 MHz was such a clear and obvious focal point which facilitated the market division in the auction.

However, a grand assignment stage would have ensured that, whatever the amounts of 3.6–3.8 GHz spectrum obtained in the principal stage, they would form part of a contiguous set of frequencies for each operator at the end of the auction. Bidders could have therefore expressed their underlying values for the spectrum. The strength of the focal point in the 2021 auction would have been reduced. But a significant risk of market division to achieve 40/40/40 MHz would still have remained, reflecting not only its symmetry but also its plausibility as a desired (and efficient) outcome.

A grand assignment stage was debated during the policy development process for the 2021 auction. The regulator accepted that the economic benefits could exceed the costs, but placed weight on some opposing arguments. H3G's potential commercial gain from post-auction trading would have been removed. There could have been an adverse effect on licensees' certainty over their spectrum rights. The alternative policy approach adopted of post-auction trading was less onerous.[14] A grand assignment stage was also contentious with operators, some favouring it and others opposed. It could have been challenged in litigation, causing complication and possible delay.

These counter-arguments to the advantages of a grand assignment stage have weaknesses. The effect on H3G is not an economic efficiency concern. Any effect on future spectrum rights would be mitigated by the very particular distinguishing features of the defragmentation issue in this case. And more than a year after the auction, trading had not achieved full defragmentation.

Conclusions

The UK's high-stakes auctions show varied experiences in revenues, strategic bidding, surprise outcomes, and mistakes. The regulator's careful design choices assisted the auctions to achieve outcomes that were generally desirable for both auction and output efficiency. Valuable lessons for future auctions were learned in attempting to replicate successes and avoid recurring problems. However, bidders also learned from their experiences, so regulators must constantly update their analyses and wherever possible anticipate new problems.

In shaping how auctions develop once under way, the regulator will need to trade off enough granularity and time for bidders to make decisions to promote auction efficiency against longer auctions sometimes reducing output efficiency through delayed benefits to consumers. Where spectrum licences can be sold or swapped outside of the primary allocation in auctions themselves, spectrum trading can be a useful supplement to achieve welfare-improving adjustments to allocations. But the *multilateral* procedure and clearinghouse involved in auctions can generally obtain more for economic efficiency than relying on a process of *bilateral*, uncoordinated trades.

Notes

1 Ofcom's spectrum awards archive: https://www.ofcom.org.uk/spectrum/spectrum-management/spectrum-awards.

2 Deposit arrangements were much more limited in the UK's 2000 auction. Bidders were only required to make an initial deposit of £50 million plus an additional £50 million if their bids exceeded £400 million. The consequence was that the deposit cover (the deposit as a percentage of the bid amount) for most of the auction was very low, ending up at 2.5 per cent or less.

3 For example, Rothkopf and Harstad (1994) consider a trade-off in oral auctions between size of the bid increment and costs of participation and of the auctioneer's time. Milgrom (2004, footnote 10) refers to a trade-off with transactions costs, recognising incumbents' interests in delay only in a later section analysing activity rules. David et al. (2007) examine costs of the auctioneer, revenue, and auction efficiency for online auctions.

4 See O2 'O2's customers are the 'winners' as Telefónica UK makes £500m airwaves investment to further strengthen its network', 5 April 2018, https://perma.cc/2BVD-Y9SJ, and EE 'BT's mobile business EE launches new spectrum into 5G network, as auction concludes', 27 April 2021, https://perma.cc/89B7-HGP5.

5 See ANACOM 'Daily information on the 5G auction', https://perma.cc/6YY8-QFZH.

6 The auction in Portugal started with a stage of bidding between new entrants for set-aside spectrum which lasted for eight days between 22 December 2020 and 11 January 2021. Bidding for unreserved spectrum in the next stage commenced on 14 January and ended on 27 October 2021. The duration of rounds at 60 minutes and the minimum bid increment of one per cent were specified in the auction regulations (see ANACOM 'Regulation no. 987-A/2020, of 5 November', 2020, https://perma.cc/CBF9-LX37). The regulator, ANACOM, attempted to speed up progress by changing the rules twice during the auction (see ANACOM 'Regulation no. 596-A/2021, of 30 June', 2021, https://perma.cc/285X-74PD). The first change enabled a faster schedule of shorter rounds per day, moving from the initial four rounds per day to seven rounds on days 82 to 119, up to 11, and then to 12 rounds from day 121 onwards. Later ANACOM removed the one and three per cent bid increments by raising the minimum bid increment to five per cent from day 180. The 5G capacity spectrum band (3.6 GHz) took by far the longest to resolve, and the final prices in the main lot category were eventually more than eight times larger than reserve prices.

7 See European Commission (2022, p.9) and the announcement of 5G services at NOS 'NOS is the first operator to launch 5G in Portugal', 26 November 2021, https://perma.cc/65DW-AT5X.

8 I was introduced to the approximation while at Ofcom by Paul Milgrom. The intuition can be seen by analogy with the welfare loss from excessive monopoly pricing, the so-called deadweight

loss – see Hines (1999). Its size is related to the square of the price change above the competitive level, because it depends on the magnitude of both the price change and the volume change, and both increase with a larger price difference. For spectrum auctions, the expected loss is the reduction in auction efficiency multiplied by the probability of it occurring, and both are proportional to the price increment. The approximation rests on simplifying assumptions which imply limitations in using it. The underlying theory relates to substitutes with straightforward bidding – see Milgrom (2000). With complements the analysis is more complex, including that the loss in auction efficiency can relate to multiple lots being misallocated. Within-band synergies can mean that the non-standing high bidder reduces demand in a modular amount of several lots, not just a single lot. Another simplifying assumption is that the price increment is sufficiently small that the more efficient allocation is only a slight improvement.

9 Ofcom (2018a).

10 European Commission (2010).

11 See Reuters 'Qualcomm to sell L-Band UK spectrum to Vodafone, Hutchison', 26 August 2015, https://perma.cc/8DNZ-YZTA.

12 See O2 'O2 & Vodafone customers set to receive 5G boost as companies announce deal to optimise spectrum bands', 27 April 2021, https://perma.cc/ZNE2-6X2F.

13 Some commentators have also suggested a barrier because administratively set annual fees applied to part of H3G's holdings that would be involved in the trades: see Enders Analysis 'Spectrum trading thwarted: 5G stumbling blocks endure', 3 September 2021, https://perma.cc/B6VP-3MD8

14 Ofcom (2020a, section 6).

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Afterword: Reflections for future auctions

Summary

- The analytical frameworks in this book can be applied to assist policy judgement on the set of decisions needed to design successful spectrum auctions.
- Designing auctions can benefit from a process of innovation, learning, and well-judged use of expertise. Auctions are not fixed in one or a few designs, but can be extensively reshaped in different ways by intelligent regulators, so as to cope with diverse and often problematic market situations. Some countries have preferred to manage complexity by sticking with a familiar auction format that is only incrementally tweaked. By contrast, the UK has tried to continuously evolve the regulators' toolkit in its auctions.
- While the book aspires to derive lessons about best practice, much can still be achieved by avoiding especially undesirable practices, such as not leaving scarce spectrum fallow, applying sufficient expertise to avoid auction design blunders, and refraining from overly restrictive spectrum caps.
- Auctions can also be harnessed in other public policy arenas like environmental challenges and infrastructure procurement to elicit market information which is otherwise hard to obtain, and so mitigate regulatory failure risks.

Spectrum is the lifeblood of mobile networks, delivering services that have transformed the way we live and conduct business, and accounted for 5 per cent of the world economy, more than $4 trillion, in 2020.[1] The pace of change in technology and digital lifestyles offers the promise of exciting future developments, even if some could potentially also be unsettling. To unlock the dynamic future and address economic and societal challenges, an approach to spectrum management should form part of a coherent vision for designing markets to deliver wide-ranging benefits to the public as consumers, citizens and taxpayers, and to industry and the wider economy. We should not be slaves to an immutable 'market', because markets come in all shapes and sizes. This book shows that by applying

How to cite this book chapter:

Myers, Geoffrey (2023) *Spectrum Auctions: Designing markets to benefit the public, industry and the economy*, London: LSE Press, pp. 215–220. https://doi.org/10.31389/lsepress.spa.l. License: CC BY-NC-ND 4.0

expertise and paying attention to an inclusive set of public values, spectrum markets can be designed simultaneously to promote economic efficiency and public purposes through investment, innovation, competition, and universal connectivity.

Using analytical frameworks to make structured judgements

There are many regulatory decisions in designing an effective spectrum auction process, summarised in the 17 categories in Figure AF.1, covering prior steps before the auction (first row), designing the auction itself (second and third rows), running it (fourth row), and post-auction events (final row). Within each category there are large and small choices to fit the design decisions to the situation prevailing in a given country, the characteristics of the spectrum on offer, prevailing market conditions in the industry, and key public and political values. I hope that the preceding chapters have demonstrated that this repertoire of choices can also cope with some of the complex recurring problems of oligopolistic markets and strategic behaviour by large, well-resourced companies – problems that are likely to be permanently present for regulators in most mobile markets. Both the high-level and tailored analytical frameworks set out in preceding chapters can assist policymakers in taking balanced decisions to cope with these exceptionally difficult conditions. Analytical frameworks help to organise the relevant considerations, to structure the analysis such as identifying the most important trade-offs, and to guide decision-makers to take account of differences in circumstances within a consistent overall approach.

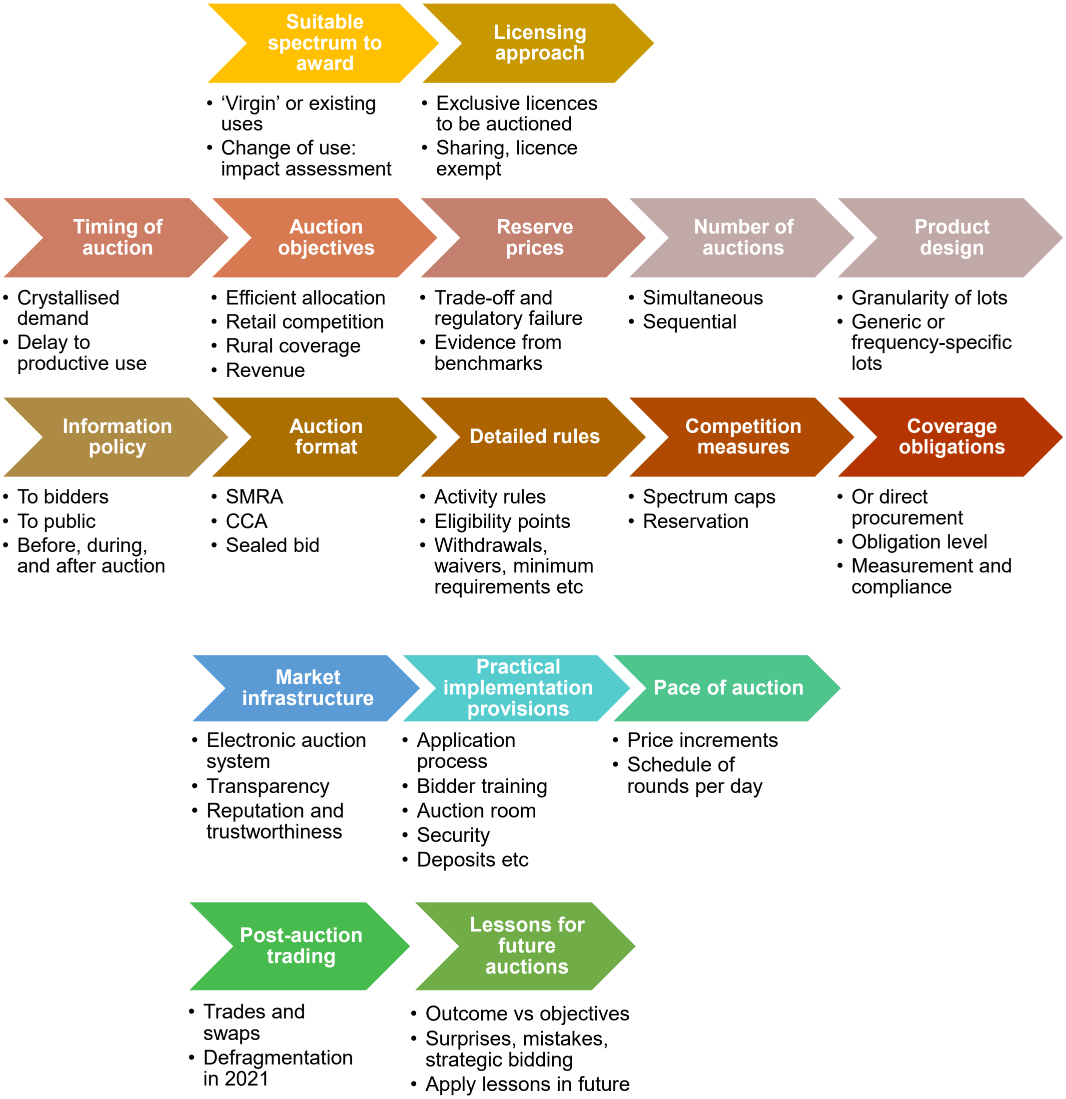
Stick or innovate?

Auctions can work out broadly as expected, be highly successful, or go embarrassingly wrong. In some countries, one regulatory response to manage this risk has been to resist innovations (which could heighten the risks of mistakes and surprises) and instead stick with a tried and trusted design across different circumstances, like backing the same horse on different racecourses. For instance, this is the route that the German regulator has generally chosen, which does not avoid risk but instead shifts it away from using untested auction features, and towards a potential loss of effectiveness or unintended consequences arising from a design that may not be sufficiently attuned to the particular situation. Some German auctions have seen very evident strategic bidding, such as signalling and market division by large firms (see Section 8.3), and others have come close to creating undesirable outcomes for economic efficiency, although these have mostly been avoided.[2]

By contrast, the UK's path has been very different, choosing an adaptive, horses-for-courses approach. Each stage of the UK's auction development has included some innovative elements, with a challenge of risk and reward. For example, the 2013 auction used a complex CCA design including several new features, which some stakeholders considered too complicated. The complexities for the more minor issues did not pay off. But the main sources of complication seemed justified: package bidding allowed bidders to express their synergistic values; and the flexibility of reservation in spectrum floors mitigated regulatory failure.

There are pros and cons, but my argument unashamedly favours evolution and innovation in how auctions are designed and implemented, mirroring both the development of auction expertise and wider historic patterns. The USA's first spectrum auction in 1994 used a format, the SMRA, which had

Figure AF.1. Choices and decisions for a spectrum auction



Source: Author.

previously been tested in the lab but not in a live auction. It has remained the workhorse model for many subsequent auctions over the next three decades, although with significant enhancements and embellishments to learn from experience. Sometimes a challenge benefits from a fresh approach. New auction formats such as the CCA have been developed and deployed with some success, although the experience has unsurprisingly been far from problem-free. In an overarching story, such difficulties provide an opportunity for learning and improvement through well-judged use of expertise.

Avoiding undesirable practices

In seeking to derive lessons about best practice, it is important to avoid making the perfect the enemy of the good – there are substantial benefits just from avoiding especially undesirable spectrum management practices:

- Spectrum that is scarce should be put to productive use. Even short of optimal use, a second-best use is still far preferable to spectrum being left fallow, which can arise from the regulator withholding it or failing to sell it in an auction.
- Impact assessments can assist decision-making without having to be elaborate. Much can be achieved just by bringing organised thinking and available evidence to bear, and by placing impact assessments in their proper role as a guide for judgement, not as providing an abstruse 'black-box' answer.
- Measures to promote downstream competition are important. But their formulation should also reflect the risks of regulatory failure. Examples are avoiding overly restrictive caps or unnecessary reservations that substantially narrow down allocation possibilities and unduly limit rivalry in the auction itself.
- Onerous coverage obligations on all licences in auctions are not the only way to achieve improved mobile coverage. Direct procurement or a more targeted approach can sometimes achieve more in practice for people on the ground.
- While there are sophisticated analytical questions in auction design, the highest priority is to get the basics right. An example is to avoid reserve prices that are too high, and instead rely on competition in the auction to set prices – even if bidding rivalry is weak, it is still desirable to get the spectrum into productive use.
- Applying sufficient expertise can avoid many design blunders, which can be caused by failing to respect key requirements like nurturing trust, providing bidders with information and flexibility to make their decisions, and maintaining an appropriate pace to the auction such as avoiding excessively small price increments. In addition, the regulator should be sure to represent interests that are not 'in the room', especially safeguarding consumer benefits and public value.

The wider relevance of auctions

A fundamental feature of well-designed auctions is that they can incentivise powerful commercial actors like mobile phone companies to reveal information about their preferences and intrinsic values. While talk is cheap, auctions bids are binding commitments. Market design solutions can harness auctions to elicit otherwise unavailable market information, such as reliable data on the opportunity cost of policy alternatives. The 2016–17 incentive auction in the USA is one example of this class of solutions, revealing information on the costs and benefits of different amounts of band clearance (see Section 6.1). The choice of spectrum floor in the UK's 2013 auction used information from bids to assess the benefits and opportunity costs of alternatives, mitigating the risk of regulatory failure from choosing the wrong spectrum to reserve to promote downstream competition (see Section 10.1). In addition, the UK regulator proposed in 2018 to unbundle coverage obligations and use auction bids to obtain better information about their costs, so that part of the cost-benefit analysis could be conducted within the auction itself on the number and level of obligations (see Section 10.2). Critics might say that spectrum floors were affected by strategic bidding, illustrating problems of auctions, and that the coverage obligation case was theoretical and contentious (for instance, it was strongly opposed by mobile operators). There is something to both of these criticisms. It is important to balance enthusiasm for the strengths of auctions with recognition of their limitations.

However, in my view, the downsides of this use of auctions do not overturn the wider advantages. Strategic bidding is an occupational hazard in auctions with a small number of bidders. But the evidence revealed in the 2013 auction is still consistent with the economically efficient choice of spectrum floor having been made, despite H3G's bid strategy (designed to ensure that it only paid the reserve price). Without the use of spectrum floors, it is likely that the regulator would have made the wrong choice of spectrum to be reserved. Unbundled coverage obligations were not implemented in the UK, and again strategic bidding could affect the efficiency of the cost-benefit choices in such an auction. However, this design proposal built on established insights about combining buying and selling within the same auction. New solutions face opposition and sometimes need refinement. This is not a strong argument against innovation, but in favour of learning, if the prize is worthwhile.

Furthermore, there is wider potential to utilise auctions to surface reliable information in complex market situations, and thus reach better-informed policy decisions – going well beyond spectrum auctions. One example is how prices in markets for pollution control (such as permits or offsets) can provide better cost information, assisting environmental policymakers to reach an improved balance between costs and benefits.[3] In many cases this could justify tightening the regulation in order to permit less pollution, mitigating a common regulatory failure of overestimating producers' costs of making changes.[4]

Another potential area is in public procurement. The public agency procuring major infrastructure projects, some potentially costing billions of pounds, could in some cases improve the balance between benefits and costs by using an auction to determine the choice of contract duration.[5] This is somewhat similar to the proposal for unbundled coverage obligations. Both relate to procurement, and involve the government or regulator specifying the benefits side of the equation. Auction bids then provide information on the cost side, in this case that different contract durations may vary in their financing costs. Improving procurement choices from better information about costs can deliver benefits for the public, industry, and the economy.

Other potential areas of application for sophisticated market design may take time to come to fruition. Different aspects of timing matter for successful markets, and similarly for ideas to gain traction they need to be timely and presented in ways that capture the moment. Ronald Coase was ahead of the policymakers in proposing auctions for spectrum in 1959, and it took more than thirty years for his idea to be taken up. A great deal more is now understood about how to harness market mechanisms for widespread benefits and public value. However, economic activity fits within social contexts, and the 'mood of the times' in public policy is not always conducive to an expansion of the remit of markets. Realising the wider potential indicated here will require not only developing further our market design know-how, but also a wider set of skills in public value creation and policymaking processes.

Notes

1. See GSMA 'Mobile Economy 2021: Infographic', https://perma.cc/P65Z-RENQ 🔓.
2. Jehiel and Moldovanu (2003, section 4.4.5), and Cramton and Ockenfels (2017).
3. Kwerel (1977), McMillan (2002, chapter 14), and Shapiro and Walker (2020). The market mechanisms could include auctions and trading markets (see Section 6.2).

[4] Harrington, Morgenstern and Nelson (2000).

[5] Greve and Pollitt (2017).

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

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

A1 Supplementary information on UK auction formats and competition measures

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

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

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

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

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

Source: Author from Ofcom auction documents.

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

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

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

The UK's first spectrum auction divided opinion, some regarding the high prices and boost to mobile competition from a new entrant as a success, and others bemoaning overpayment for spectrum as a debacle causing risks of reduced investment and higher consumer prices. 3G technology did not live up to the hype, fuelling the view that operators overpaid for the spectrum. It remains controversial whether there was an adverse effect on investment and prices. Yet there is evidence of an efficient allocation of spectrum to the right winners, and the promotion of mobile competition through a new entrant has been a long-lived benefit.

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

Bidding and outcomes

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

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

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

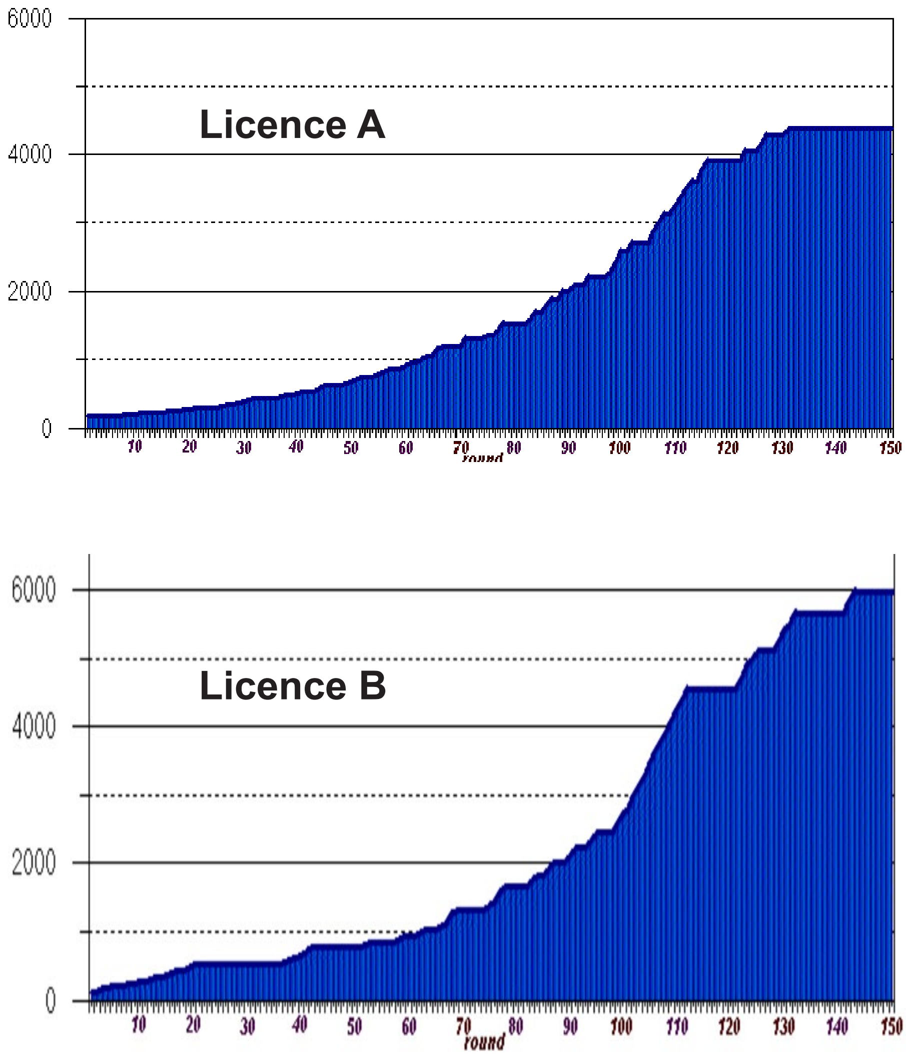
Operator	2.1 GHz spectrum lots[1]	Price per MHz in £ million	Total price in £ million	Reserve price in £ million
Orange	E, 20 MHz	205	4,095	89
BT	C, 20 MHz	202	4,030	89
One2One	D, 20 MHz	200	4,003	89
Vodafone	B, 30 MHz	199	5,964	107
TIW	A, 30 MHz	146	4,385	125
Total or average	120 MHz	187	22,477	500

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

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

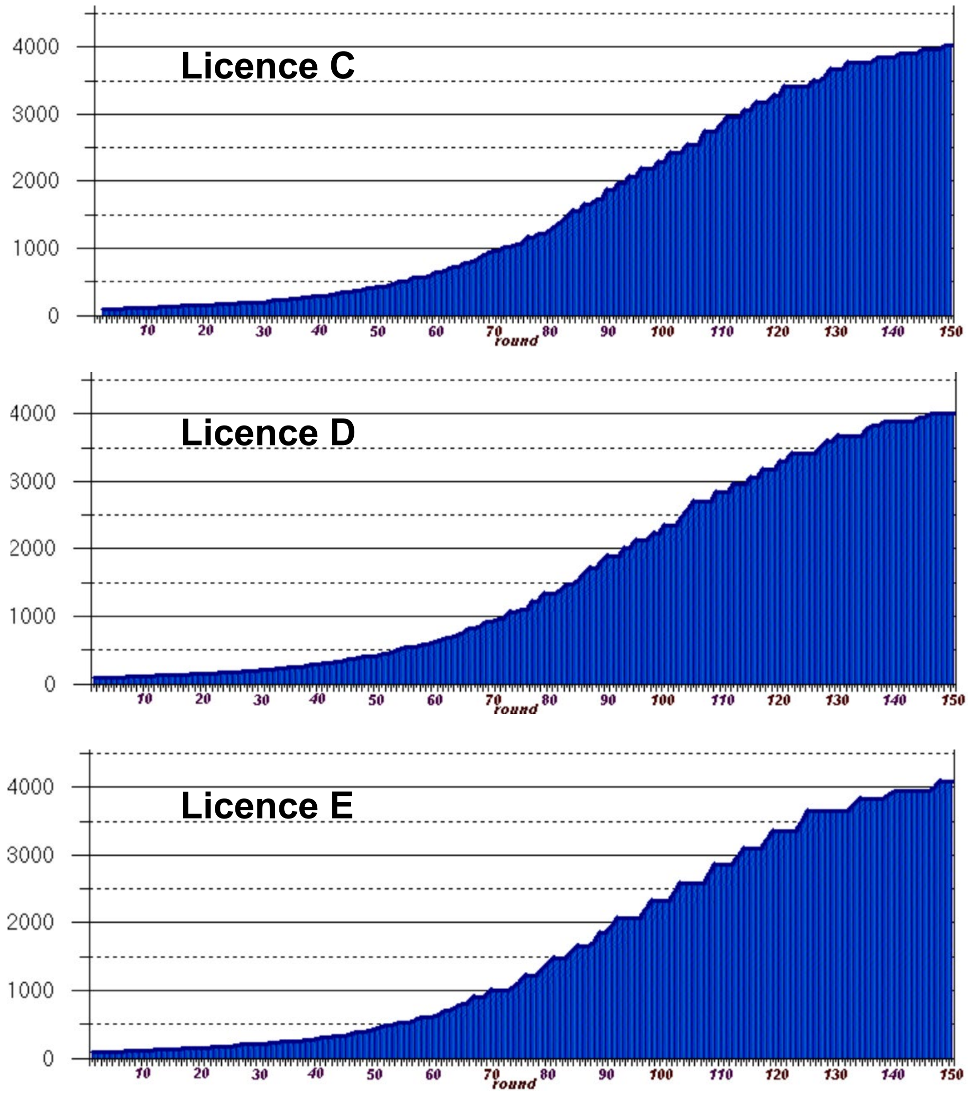
For the two larger licences, A and B, Figure A2.2 sets out the evolution of prices on the vertical axis across the bidding rounds shown on the horizontal axis. The competition between potential new entrants for licence A was resolved in round 132, when NTL Mobile switched away and instead bid for one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

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



Source: Radiocommunications Agency auction documents.[2]

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



Source: Radiocommunications Agency auction documents.

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

Figure A2.3 shows the round prices for C, D, and E, the three smaller licences. The prices for each of these licences increased in a similar way to reach just over £4,000 million by the end of the auction when NTL Mobile eventually dropped out. The substitutability of these licences contributed to the similar pattern, because non-standing high bidders switched between licences based on their relative prices.

Surprises, mistakes, strategic bidding, and economic efficiency

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

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

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

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

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

Lessons learned

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

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

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

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

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

How previous lessons were applied

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

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

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

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

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

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

Bidding and outcomes

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

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

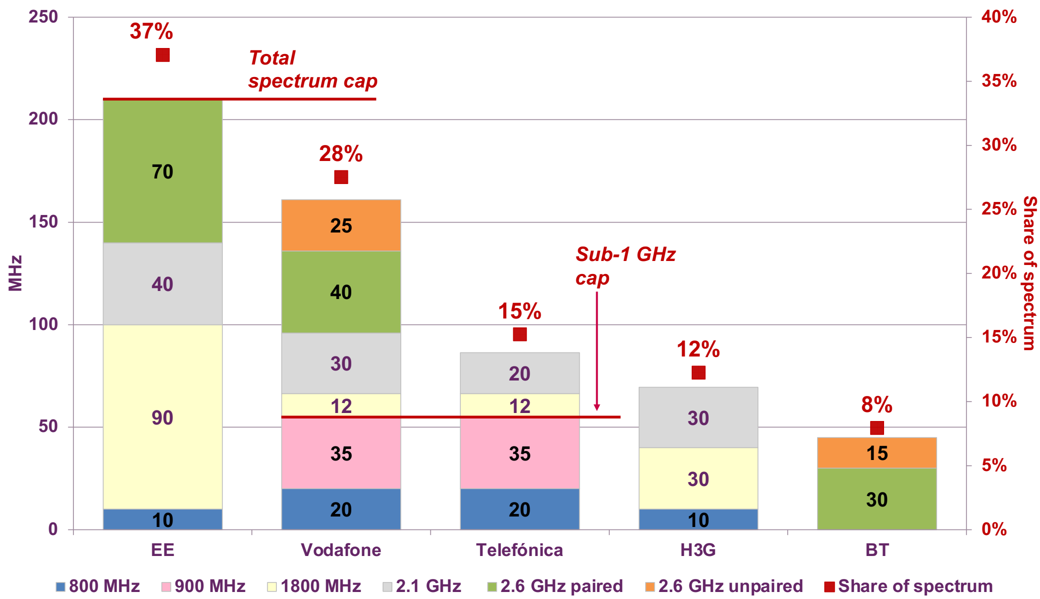
The reserved spectrum was won by H3G (see Section 10.1). The other competition measures of two spectrum caps were also important and turned out to be binding constraints, as shown in

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

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

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

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



Source: Author from Ofcom auction documents.

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

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

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

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

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

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

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

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

Surprises, mistakes, strategic bidding, and economic efficiency

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

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

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

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

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

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

Lessons learned

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

There is a good case that the *complexity* of the CCA format arising from package bidding was justified for the 2013 auction because of the cross-band synergies. But where these synergies are less important, a simpler format is preferable. An additional complication of spectrum floors provided justified flexibility because the evidence is at least consistent with a more economically efficient choice of reserved spectrum than under set-aside (see Section 10.1). However, a further complication was less successful. The design for the 2013 auction included competition for part of the 2.6 GHz paired spectrum between individual standard-power and multiple concurrent low-power licences, only one of which could win. The basic concept was to use auction bids for a licensing policy choice which was not self-evident before the auction as between exclusive and shared use of this spectrum. But there was little evidence of intrinsic-value bids for the low-power licences, suggesting (with hindsight) that it would have been better for the regulator to take the policy decision instead of leaving it for auction bids to decide. The bidding did not directly affect the outcome, but it was another contributor to the lack of price and package discovery in the clock phase.[20] A lesson for the regulator from this mixed experience in 2013 auction was to use the 'heavy machinery' of the CCA only when it is really needed.

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

A4 Bidding and outcomes in the 2018 auction for PSSR spectrum

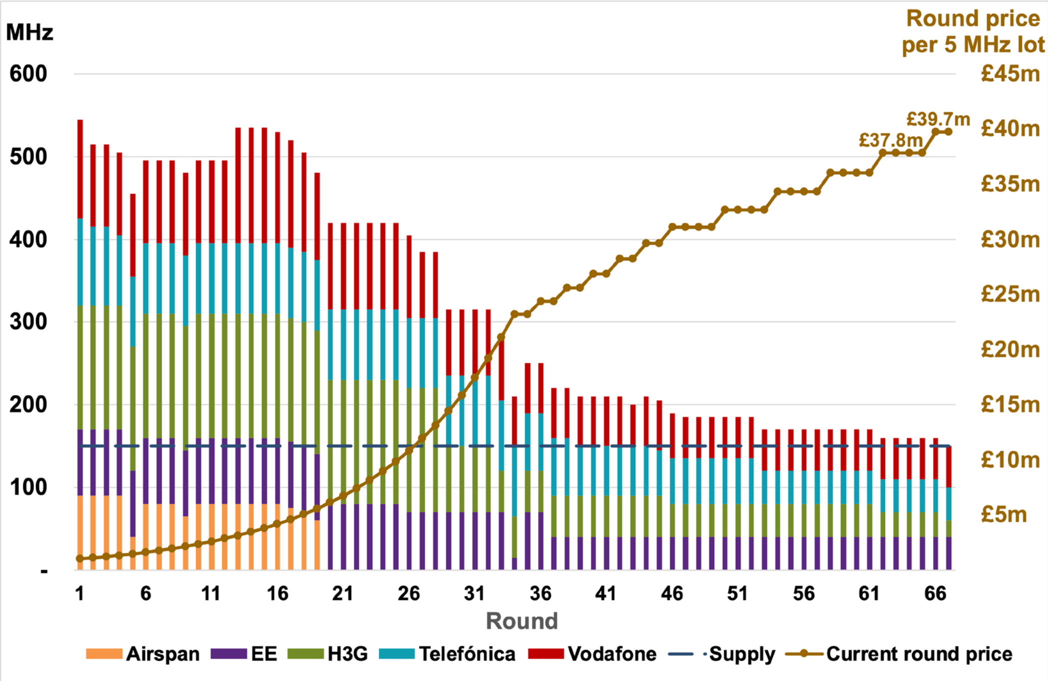
The next auction in 2018 included bands from Public Sector Spectrum Release (PSSR) by the Ministry of Defence. One band on offer (2.3 GHz spectrum) was immediately useable for 4G, and the other (3.4–3.6 GHz) was prime spectrum for early 5G deployments which were expected to start a year or so after the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

How previous lessons were applied

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

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

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



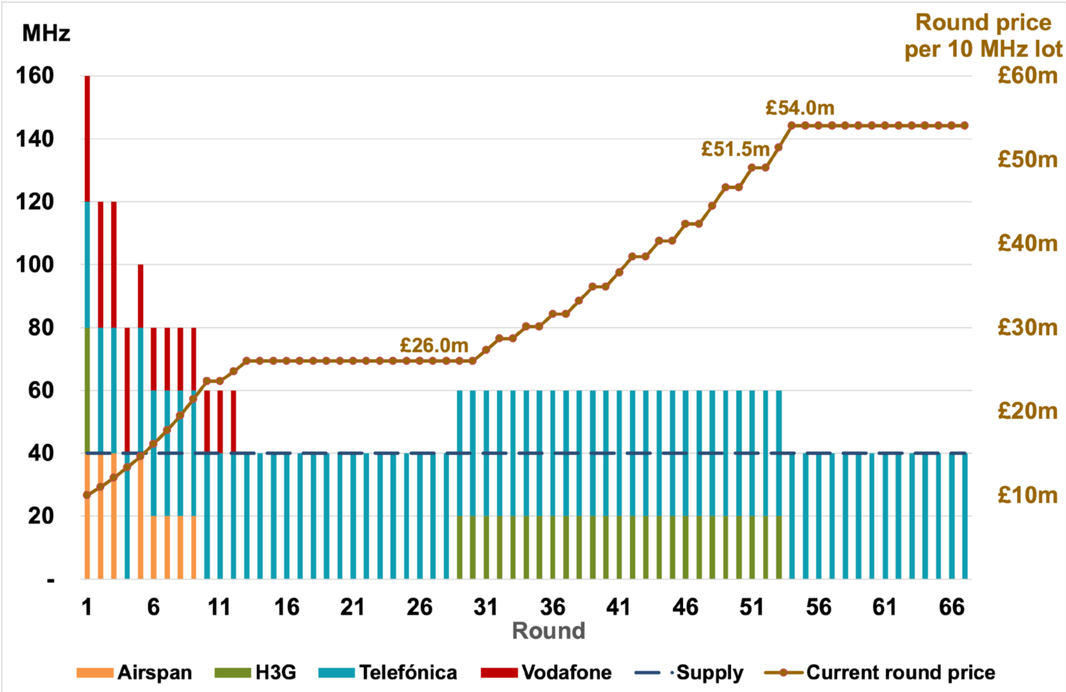
Source: Author from Ofcom auction documents.
Note: Waivers were used by Airspan in round 4, EE in round 34, and Vodafone in round 43.

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

Bidding and outcomes

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

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



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

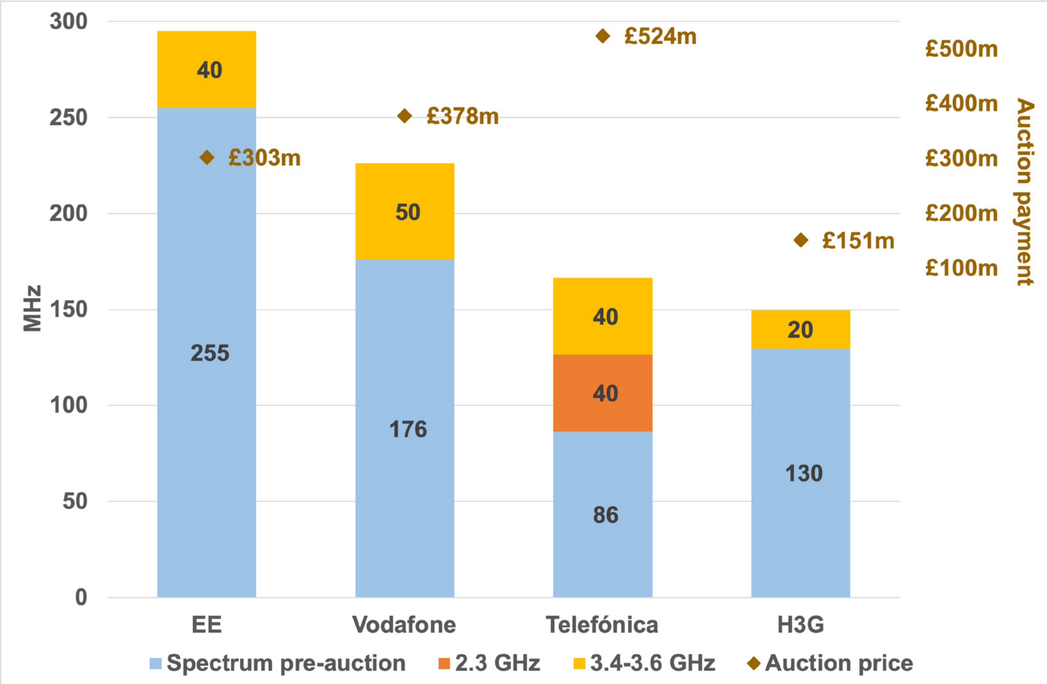
reduced their demand until round 67 when H3G dropped its bid to 20 MHz at a price of £39.7 million per 5 MHz. This cleared the market, bringing aggregate demand down to match supply.

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

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

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

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



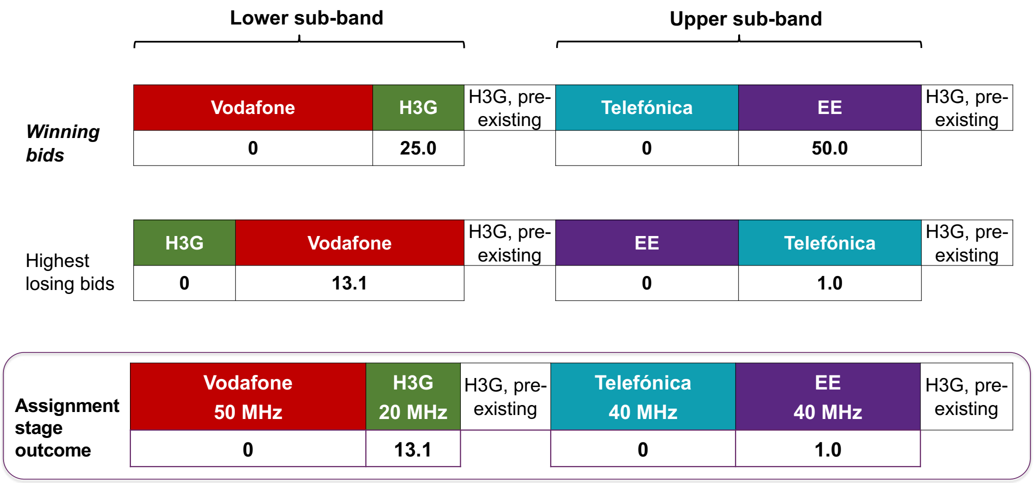
Source: Author from Ofcom auction documents.

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

Surprises, mistakes, strategic bidding, and economic efficiency

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

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



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

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

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

Lessons learned

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

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

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

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

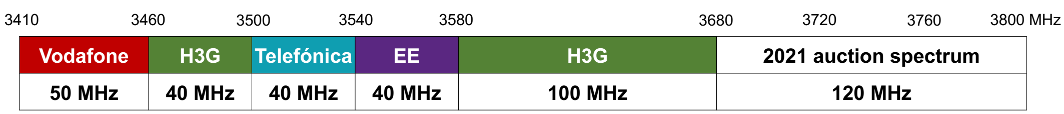
How previous lessons were applied

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

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

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

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



Source: Author.

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

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

Bidding and outcomes

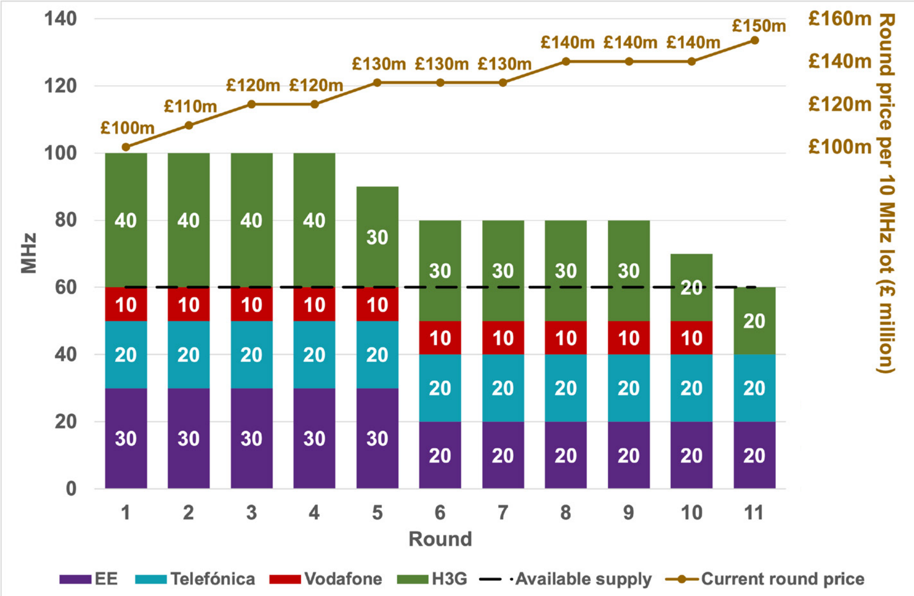
The 2021 auction was the first incumbents-only award, without any potential new entrant. (BT was not a bidder because it had taken over EE in 2016). Potential entrants had contributed to competition in previous auctions, whether going on to acquire spectrum (TIW/H3G in 2000, and BT in 2013) or dropping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

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

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

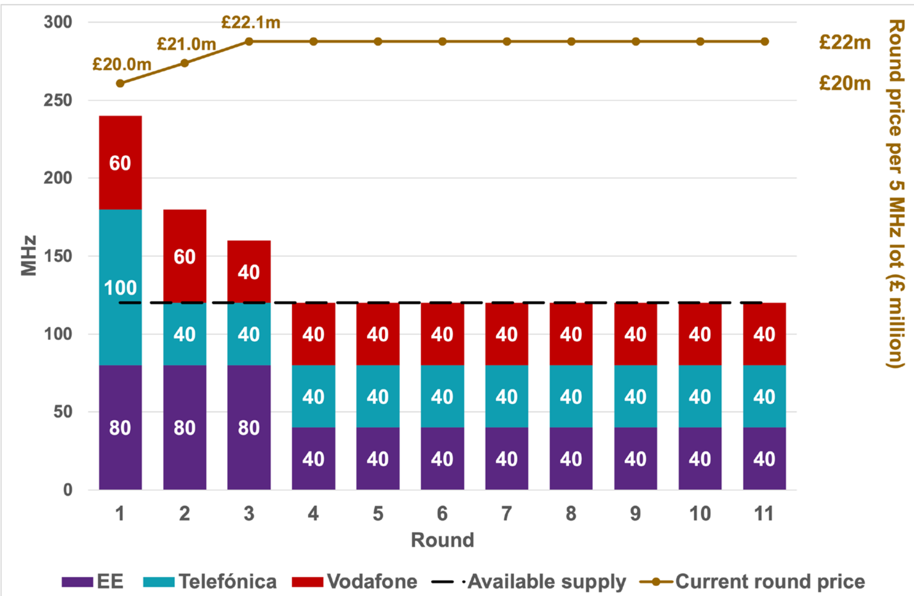
The impact of the principal stage outcome on operator's holdings is shown in Figure A5.4. EE won spectrum in all three bands in the auction, Telefónica in both high-value bands, H3G just in 700 MHz paired, and Vodafone in 3.6–3.8 GHz. As in 2018, all the operators ended with their holdings well short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

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



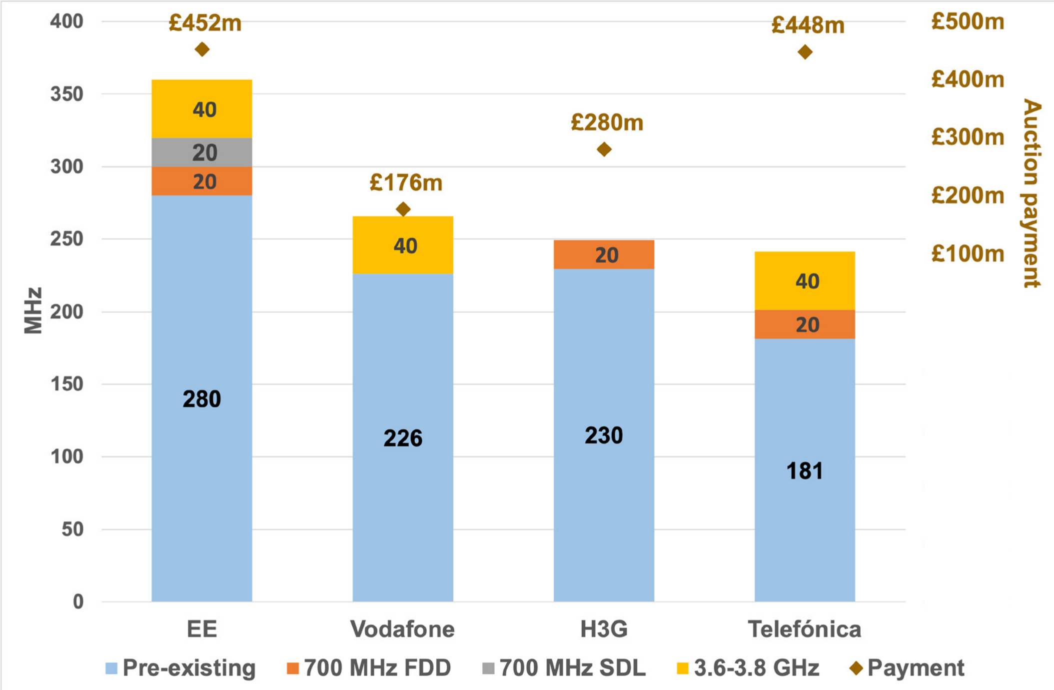
Source: Author from Ofcom auction documents.

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



Source: Author from Ofcom auction documents.

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



Source: Author from Ofcom auction documents.

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

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

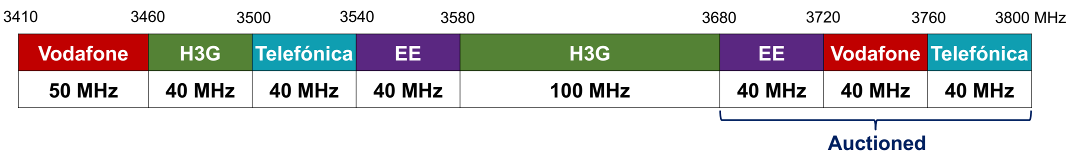
For the 3.6–3.8 GHz band the assignment stage bids were not published, but the outcome is shown on the right-hand part of Figure A5.6. Telefónica and Vodafone reached a partial agreement after a four-week negotiation period. They therefore had to be located next to each other (in the order set out in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

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

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

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

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



Source: Author from Ofcom auction documents.

Surprises, mistakes, strategic bidding, and economic efficiency

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

The 2021 auction was not at all competitive in the other two bands. There was strong evidence that bidders engaged in coordinated market division (tacit collusion) in the 3.6–3.8 GHz band. The bid pattern showed three operators taking it in turns to reduce their demand to the focal point of 40 MHz each to win spectrum at low prices — Telefónica in round 2 inviting Vodafone and EE to drop their demand, which they then did in the next two rounds.[26] The equal allocation of spectrum was a crystal–clear focal point, because it was both a desirable amount for each firm and would allow post-auction swaps to achieve defragmentation. The price paid of £21 million per 5 MHz was only one price increment above the reserve price. It was 45 per cent lower than the £37.8 million for the very similar 3.4–3.6 GHz spectrum in the 2018 auction.[27] Limited competition in the auction therefore depressed prices and revenue.

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

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

Lessons learned

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

Could auction revenue have been increased by a different design? The regulator could have set a higher reserve price for the 3.6–3.8 GHz band, given the quality and relevance of the available benchmark of the 3.4–3.6 GHz price from the previous auction in 2018. Yet there was much more uncertainty about the market value of the other bands – the low reserve price for 700 MHz SDL proved to be justified, and it was not clear that the reserve price for 700 MHz paired spectrum affected the outcome. A further possibility would have been to use the alternative CCA format which is generally much less vulnerable to market division than SMRAs (see Section 8.3), and could perhaps have made more of the limited bidding competition that existed. However, the same unusually clear focal point would still have existed to assist a three-way market division by EE, Telefónica, and Vodafone.[29] In addition, the CCA's heavy machinery could have had downsides, and the UK regulator's duties excluded revenue-raising as an auction objective in any case.

Notes

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

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

3 National Audit Office (2001).

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

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

6 Swann and Tether (2003).

7 Börgers and Dustmann (2005).

8 Cramton (2001, p.53).

9 Maldoom (2005).

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

11 Cramton (2013, section 4).

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

13 Ofcom (2017, annex 4).

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

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

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

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

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

[18] National Audit Office (2014).

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

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

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

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

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

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

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

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

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

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

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

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Note: means an open access publication.

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Annex B: Further explanation of the Combinatorial Clock Auction (CCA) format and bidding in the UK's 2013 auction

The CCA format, described in Chapter 8, includes some complex features. This annex provides further explanation of key aspects of the design, illustrated by practical examples from the UK's CCA in 2013: how bidding in a CCA operates; the second-price rules used to set principal stage prices, which have also been adopted for assignment stages in auctions using generic lots in the UK and elsewhere; and the CCA's complicated activity rules.

B1 Bidding in the CCA format

In a CCA the participating firms make their package bids in two component stages – the clock rounds followed by the supplementary bids round, which together comprise the principal stage determining the amount of each band of spectrum won by the bidders. After receiving all the principal stage bids made by the operators, the regulator then works out the winning combination of packages. I go through each of these three parts of the CCA format (clock rounds, supplementary bids round, and computation of the winners), using bids from the 2013 auction to explain the nature of package bidding, to show bids that incorporated synergy values, and to demonstrate the risk of surprise outcomes for the operators.

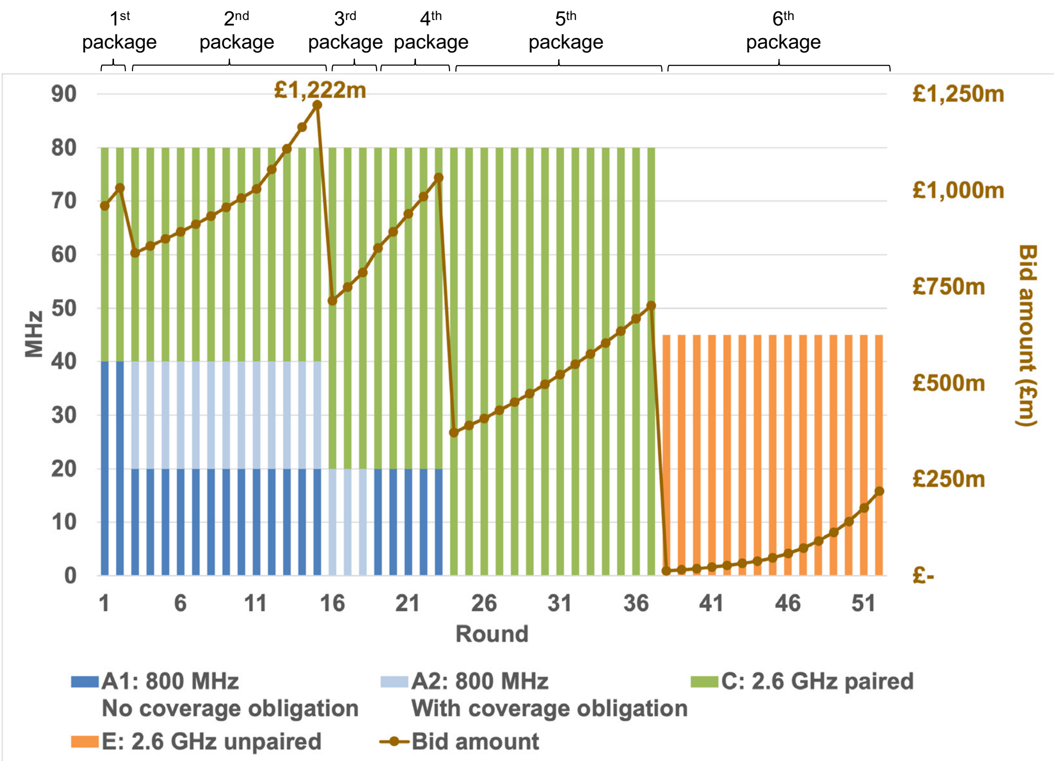
There were four main lot categories included in the 2013 auction:

- For the coverage spectrum in the 800 MHz band, one category (labelled A2) was for a single lot of 20 MHz with an attached coverage obligation, and a second category contained four lots of 10 MHz each without any coverage obligation (A1).
- For the capacity spectrum in the 2.6 GHz bands, paired spectrum was in 14 lots of 10 MHz (category C) and unpaired spectrum was in nine lots of 5 MHz (category E).[1]

Clock stage

To illustrate the nature of package bids in the clock stage of a CCA, Figure B1.1 shows the bids in 2013 by one of the operators, EE, for six different packages of spectrum across the 52 clock rounds. The stacked bars in the columns for each round show the mix of bands that EE sought, and the bid amounts are shown by the brown line. In the first two rounds, EE bid for 40 MHz in each of the 800 MHz and 2.6 GHz paired bands (categories A1 and C). In rounds 3 to 15 it bid for the same spectrum amounts, but switched half of its 800 MHz demand to the spectrum with a coverage obligation (category A2). Its largest clock bid amount of £1,222 million was in round 15. Then in rounds 16 to 37, EE bid for the same total amount of spectrum, but switched the package composition from 800 MHz to more of the lower-priced 2.6 GHz paired in each of rounds 16 and 24. It also switched in round 19 between 800 MHz with and without a coverage obligation. From round 38 EE made another switch

Figure B1.1. Package bids by EE in each clock round in the 2013 auction



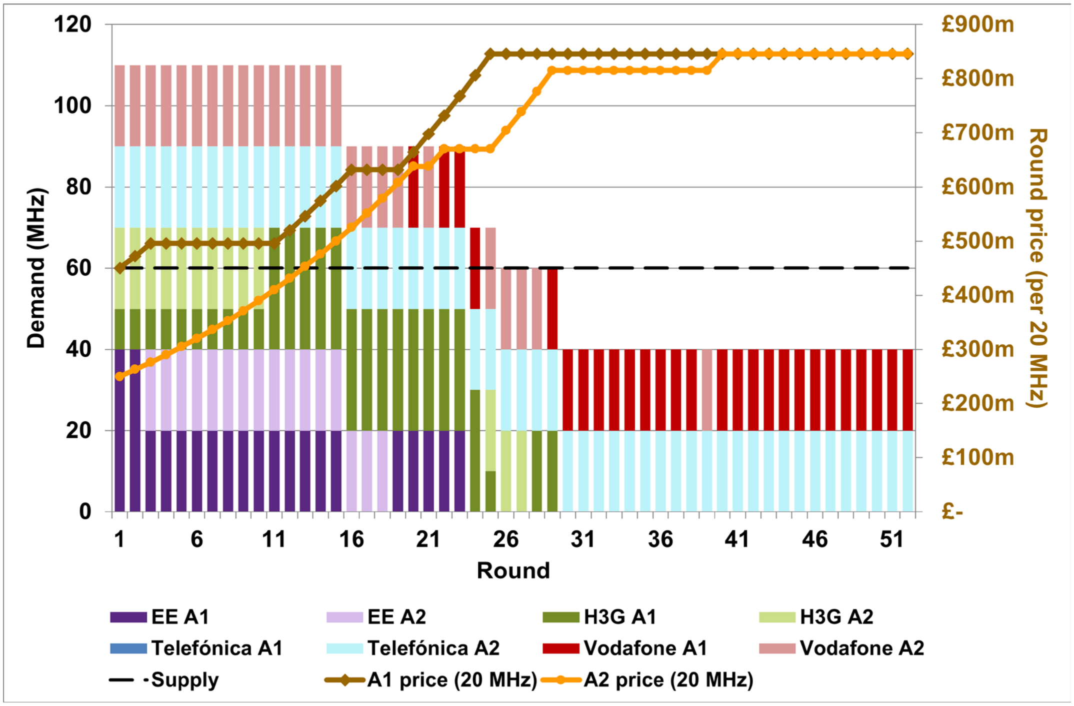
Source: Author from Ofcom auction documents.
Note: EE's largest bid amount is shown rounded to the nearest £ million.

to a smaller amount of 2.6 GHz unpaired spectrum (category E). Overall, EE's different packages displayed just one change in the amount of spectrum, but major changes across the rounds in the package composition by band.

The progress in the clock stage in a CCA depends on the package bids from all bidders. When there is excess demand in any category, the price is increased in the next round. In the 2013 auction, the round price increases are reflected in the rising segments for EE's bid amount line in Figure B1.1 (before EE reduced its bid amounts by switching several times to packages with lower-priced spectrum).

The clock stage in a CCA ends when there is no excess demand in any category. In the 2013 auction there were 52 clock rounds. Starting with the two 800 MHz categories, it took 40 rounds for aggregate demand to settle at a level of demand that was less than supply, as shown in Figure B1.2. The colours signify different bidders, and the lighter and darker shading indicates each operator's bids for 800 MHz with the coverage obligation (A2, shown lighter) and without it (A1, in the darker shade). Some bidders switched between these categories depending on their relative prices, such as Vodafone shown in red. Telefónica set out its stall to win the single A2 lot with the coverage obligation, bidding for it in every round (the pale blue blocks). EE in purple did not bid aggressively for 800 MHz spectrum, and dropped out of the band in round 24. H3G in green only made bids in this band until round 29.

Figure B1.2. Clock bids in the 800 MHz band in 2013, showing the evolution of bids and switching between categories A1 and A2



Source: Author from Ofcom auction documents.

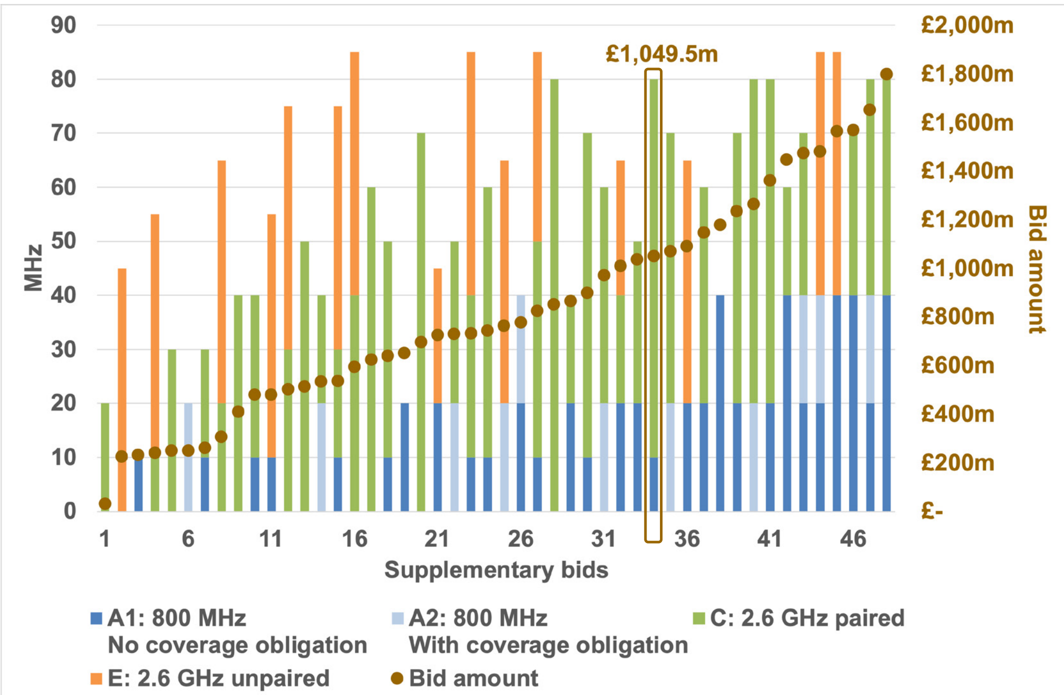
The aggregate demand for the 800 MHz band was the same as supply at 60 MHz as early as round 26. But bidding continued because in a simultaneous auction nothing is resolved until all categories are finished, and there was still excess demand for some of the spectrum. For example, the 800 MHz demand in round 26 was composed of no demand in category A1 but excess demand for the one A2 coverage lot due to bids for three lots by H3G, Telefónica, and Vodafone (shown by the paler shades for these bidders). So the price of A2 went up in the next few rounds (see the upward sloping A2 price line in orange). In response two bidders, H3G and Vodafone, switched their demand from A2 to A1. By round 29 there was no excess demand in either A1 or A2, leading to no price increases (both price lines were flat). Bidding for 800 MHz remained open because there was still excess demand in the 2.6 GHz categories, and there were a few further changes. H3G dropped out of the band in round 30, leading to excess supply of 20 MHz in A1. Vodafone switched from A1 to A2 in round 39, leading to excess demand in A2 and so a price increase in the next round that made the per MHz price of A2 as high as A1. In round 40 Vodafone switched back to A1 so that only Telefónica was bidding for A2 and *excess supply* in A1 was again at 20 MHz. There were no changes in bids or prices in the 800 MHz categories after that.

However, there was still excess demand in the 2.6 GHz categories. In 2.6 GHz paired (C), aggregate demand across five bidders was more than double the supply until round 30. It then reduced as the price increased and the last bid change was in round 41, also with a small *shortfall* of demand below supply of 10 MHz. In 2.6 GHz unpaired (E), all seven bidders were active at some point – the two smaller bidders only made bids in this band and they dropped out in clock rounds 32 (MLL) and 46 (Hong Kong Telecom). This was the lowest-value band in the auction but the last to settle in round 52. The duration of bidding in this category was in large part due to starting at a very low reserve price, only £0.1 million per 5 MHz lot. Demand was initially more than four times larger than supply, and the clock price rose to £24.4 million when the clock stage ended (see Figure B3.3 in the final section of the annex).

Supplementary bids and synergy values

After the clock rounds the next stage of the CCA format is the supplementary bids round, when each bidder can make a large number of bids for mutually exclusive packages. Examples of an operator's supplementary bids are EE's bids for 48 packages in 2013 set out in Figure B1.3, including different quantities and composition of the three spectrum bands (800 MHz in blue, 2.6 GHz paired in green, and 2.6 GHz unpaired in orange) and bid amounts (shown by the brown dots). This number of package bids was more than four of the bidders – HKT and MLL (9 each), Telefónica (11), and H3G (17) – but much less than two other companies – BT (89) and Vodafone (94). In their supplementary bids operators can choose to bid for *additional packages* compared to the clock rounds. EE did so in 2013,

Figure B1.3. Package bids by EE in the supplementary bids round in 2013



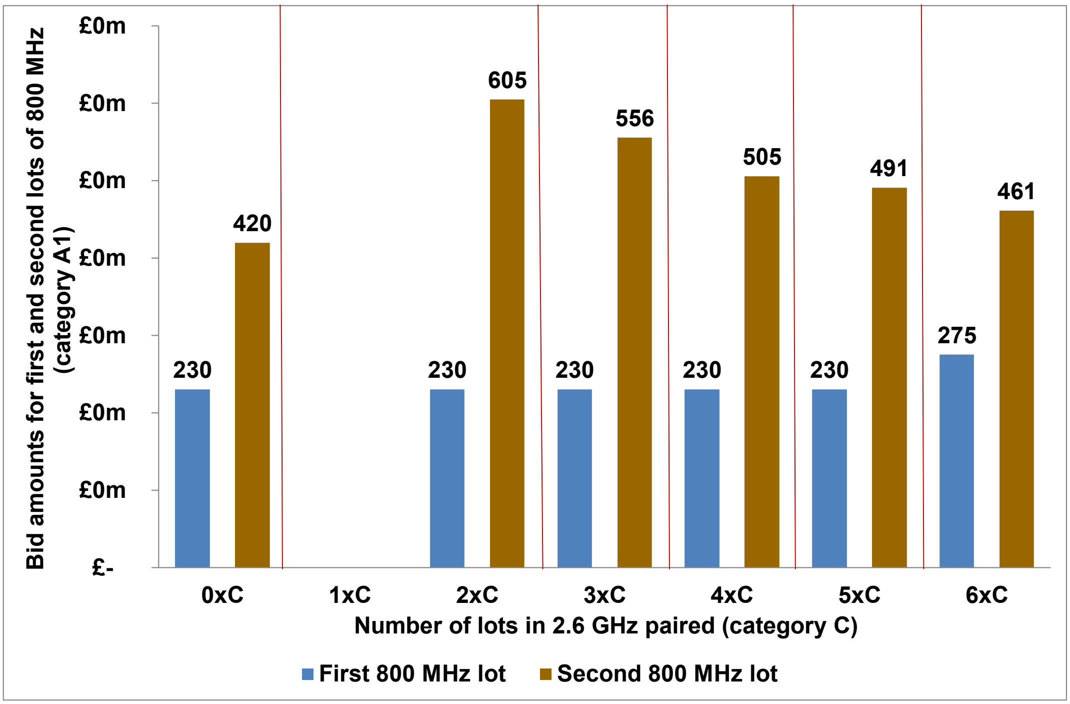
Source: Author from Ofcom auction documents.
Note: EE's winning bid amount is shown rounded to the first decimal point in £ million.

bidding for 42 further packages, including its winning bid which was not one of its six packages in the clock stage. EE's winning bid is highlighted, shown as supplementary bid 34 when arranged by bid amount as in Figure B1.3, namely £1,049.5 million for 10 MHz of 800 MHz and 70 MHz of 2.6 GHz paired (1 lot of category A1 and 7 lots of category C).

One of the advantages of package bidding in a CCA is that it enables operators to express *synergies* in their spectrum valuations. Some of the *within-band* synergies in EE's supplementary bids in 2013 are illustrated in Figure B1.4, showing pairs of incremental bid values for each of the first and second lots of 800 MHz (A1) in packages with different numbers of lots of 2.6 GHz paired (C) shown along the horizontal axis. The incremental bid values for the second 800 MHz lot (the brown bars) are much larger in every case than for the first lot (the blue bars). This rising value per MHz reflects the synergy values. For example, the largest synergy was in packages with two lots of 2.6 GHz paired (2xC):

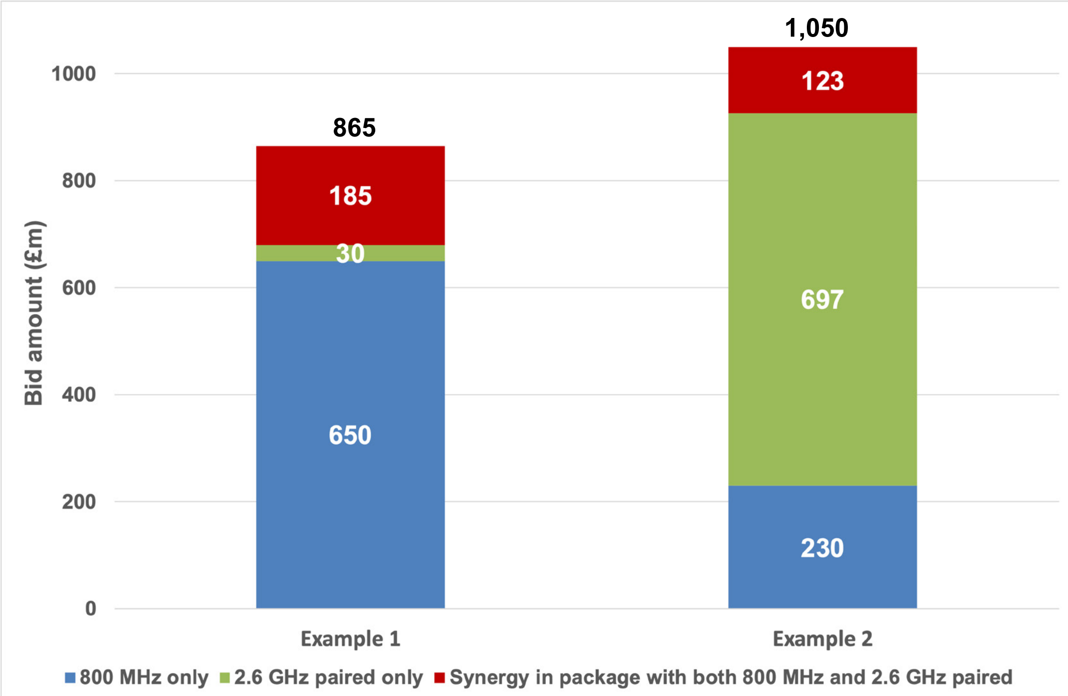
- EE bid £30 million for a package of 2xC only and £260 million for a larger multi-band package also including one lot of 800 MHz (1xA1 plus 2xC). Therefore, its incremental bid value for the first 800 MHz lot was £230 million, the amount shown in the blue bar in the second pair of incremental bid values in Figure B1.4 in the columns labelled 2xC.

Figure B1.4. Examples of within-band synergies in EE's bids in 2013, shown by rising incremental bid values between its first and second 800 MHz lots (category A1) in packages including different amounts of 2.6 GHz paired lots (category C)



Source: Author from Ofcom auction documents.
Notes: The columns for 1xC are blank because EE did not make bids for packages with 1xC.
Incremental bid values are shown rounded to the nearest £ million.

Figure B1.5. Examples of cross-band synergies in EE's package bids in 2013 for combinations of 800 MHz and 2.6 GHz paired spectrum



Source: Author from Ofcom auction documents.
Note: Bid values are shown rounded to the nearest £ million.

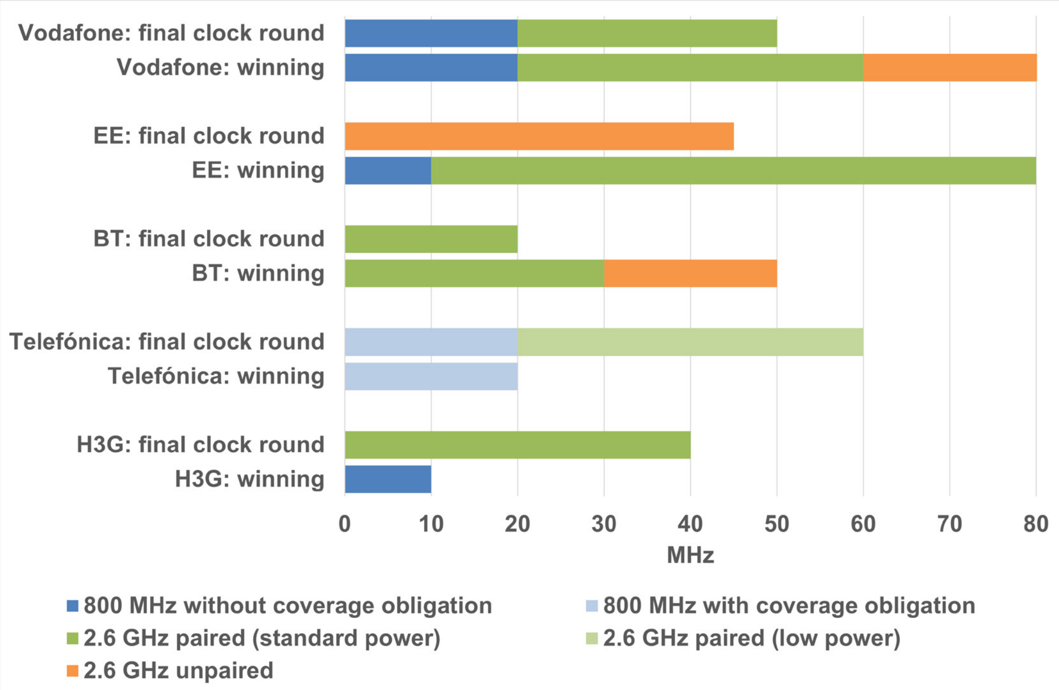
- It also bid £865 million for the larger package which included a second lot of 800 MHz, 2xA1 plus 2xC, at a much bigger incremental bid value for the second 800 MHz lot shown in the brown bar of £605 million (£865 million less £260 million).

Many of EE's bids also displayed *cross-band* synergies, of which two examples are shown in Figure B1.5. EE bid £650 million shown in the blue segment for a package of 800 MHz only (two lots, 2xA1), £30 million in the green segment for a package of 2.6 GHz paired only (two lots, 2xC), but £865 million for the larger package including both these amounts of 800 MHz and 2.6 GHz paired (2xA1 plus 2xC). This exceeded the sum of bids for the constituent smaller packages by the cross-band synergy of £185 million shown in the red segment (21 per cent of the bid of £865 million). The second example relates to EE's winning bid in the auction: it bid £230 million for 800 MHz only (in this case, for just one lot, 1xA1), £697 million for 2.6 GHz paired only (seven lots, 7xC), and £1,050 million for the larger package including both (1xA1 plus 7xC). This included a cross-band synergy of £123 million (12 per cent of £1,050 million).

Spectrum allocation outcome

The spectrum allocated to each operator in the CCA format is identified by an algorithm searching for the set of packages with the highest bid value among all combinations that include no more than

Figure B1.6. Comparison of winning and final clock packages of the five successful bidders in 2013



Source: Author from Ofcom auction documents.

Note: Telefónica's final clock package included a bid for a concurrent low-power licence for a portion of the 2.6 GHz paired spectrum. Operators are shown in descending order of the spectrum amounts in their winning packages.

one package bid from each bidder and avoid exceeding the available spectrum supply. In the case of the 2013 auction, all winning packages after the supplementary bids round differed from those in the final clock round, as set out in the comparison by bidder in Figure B1.6. For each operator, the package of spectrum at the end of the clock stage is shown as its upper stacked bar, and the operator's winning package as its lower stacked bar. Overall, the winning packages were larger, because operators made supplementary bids for the spectrum in excess supply at the end of the clock rounds in the 800 MHz and 2.6 GHz paired bands. However, the changes in the packages were much more extensive than just adding this spectrum to bidders' final clock round packages. Vodafone, EE, and BT won much larger amounts of spectrum than in their packages at the end of the clock stage, and Telefónica's and H3G's winning packages were significantly smaller. EE and H3G also won spectrum in entirely different bands.

A key function of the clock stage of a CCA is to assist the bidders through feedback from the auction providing price and package discovery. However, in practice in 2013 the large changes in packages between the end of the clock stage and the final outcome highlighted the limited usefulness of *package* discovery during the clock stage of that auction. In addition, the limited *price* discovery in the clock stage in 2013 is indicated by the difference in band prices in Figure B1.7 between the prices in the final clock round, and the much lower principal stage prices for the winning packages after the supplementary bids, which were based on the highest losing bids – see the next section of this annex.[2]

Some of the reasons for the limited package and price discovery in 2013 were because of the choice of activity rules – see the final section of the annex.

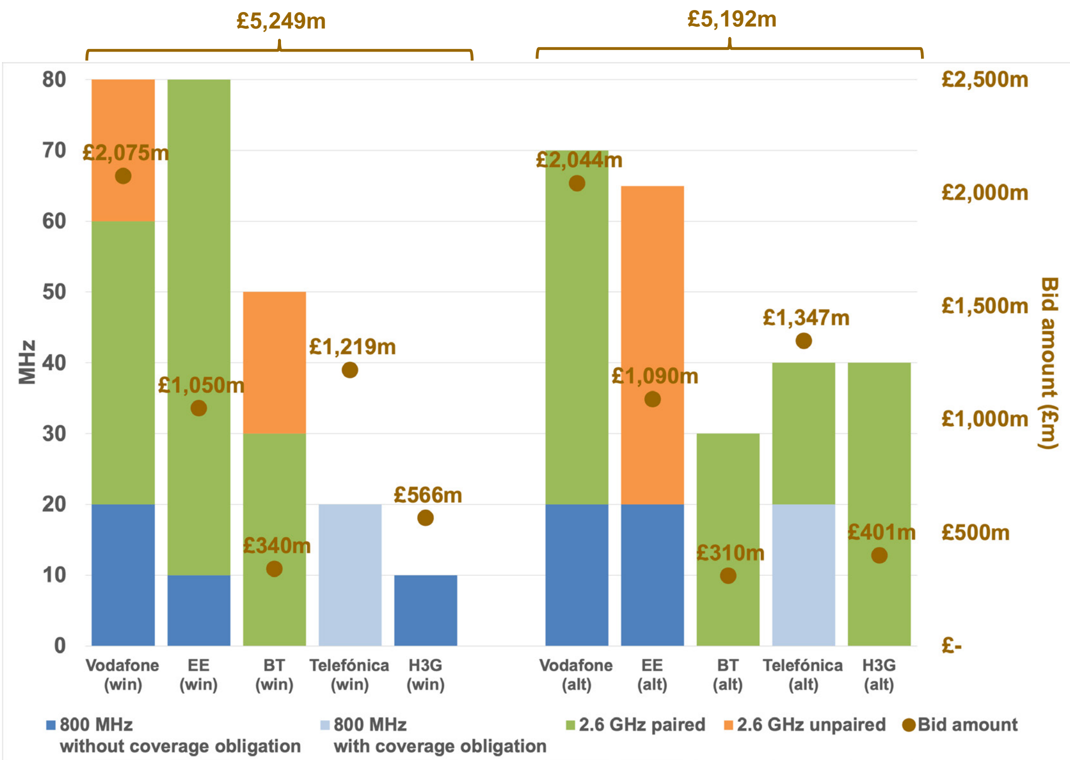
When determining the winning set of packages in a CCA, alternative candidate combinations can involve large not marginal differences in spectrum allocations between bidders. An illustration is two candidate outcomes in the 2013 auction and their bid amounts shown in Figure B1.8, labelled 'win'

Figure B1.7. Comparison of prices in £ million per MHz in the final clock round and for the winning packages after supplementary bids in 2013

	800 MHz	2.6 GHz	
		Paired	Unpaired
Prices in the final clock round	42.3	9.2	2.4
Principal stage prices for the winning packages*	26.9	5.0	1.3

Source: Author from Ofcom auction documents.
Notes: * Principal stage prices (after supplementary bids) were set by package, with no uniquely correct way to decompose them by band. The figure shown for each band is the 'linear reference price' per MHz.[3]
Prices are shown rounded to the first decimal point in £ million.

Figure B1.8. Comparison of the winning combination of package bids and an alternative combination in 2013



Source: Author from Ofcom auction documents.
Note: Bid amounts are shown rounded to the nearest £ million. Operators are shown in descending order of the spectrum amounts in their winning packages.

and 'alt' – these were the winning combination and the losing combination for the choice of alternative spectrum floors (reserved spectrum) obtained by H3G (see Section 10.1). Each combination includes one package bid from the five winning operators, and both would have sold all the spectrum. The winning combination on the left-hand side had total bid value of £5,249 million. The total bid value of the alternative on the right-hand side was only 1 per cent less at £5,192 million. In order to win, the total bid value in the alternative combination would have needed to be slightly higher to exceed the winning combination. If so, the spectrum allocation would have been very different: H3G with 40 MHz instead of 10 MHz and in a different band – 2.6 GHz paired instead of 800 MHz; Telefónica with 20 MHz more by adding 2.6 GHz paired spectrum to the 800 MHz with the coverage obligation; and Vodafone, EE, and BT with less spectrum in their packages and also a different composition of bands, such as EE having 10 MHz more of the 800 MHz band but only 45 MHz of the 2.6 GHz unpaired spectrum instead of 70 MHz in the 2.6 GHz paired band. The large differences between these two candidate outcomes emphasised the scope for *surprise outcomes* in the CCA.

B2 Second-price rules

After identifying the winning set of packages in the CCA, the regulator then determines the prices to be paid by the successful bidders, using information from the highest losing bids. To explain the specific version of the second-price rules used in the CCA format, I build up the logic from individual to collective opportunity cost along with examples, both illustrative and from the 2013 auction. The same pricing rule is often also adopted to set the prices in assignment stages, as in the UK in 2013, 2018, and 2021.

Vickrey prices: individual opportunity cost

The format chosen for the assignment stage in UK auctions and elsewhere in many cases is a sealed-bid, combinatorial, second-price auction for each band. This is a simpler version of the supplementary bids round of the CCA format. Both are related to a 'Vickrey auction' (named after its inventor, the Nobel Memorial Prize winner William Vickrey).[4] It has desirable theoretical properties of providing incentives for straightforward bidding, because the prices paid by the winners are set by bids made by other bidders (highest losing bids) and so are independent of a firm's own bids. Vickrey prices are set at individual opportunity cost, the lowest bid a winning operator could make before it fails to remain a winner because of the highest losing bids. An equivalent way to express this price is that each winning bidder obtains a discount on its winning bid (the 'Vickrey discount') that is equal to the value it brings to the auction (which in turn is given by the difference in total bid value with and without the bidder). However, Vickrey auctions also have well-known deficiencies.[5] For example, they can result in very low prices, and are open to gaming such as collusion.[6]

A simple example of bidder valuations is shown in Figure B2.1 for three bidders, called Camel, Dolphin, and Elephant. Dolphin and Elephant view the two items, A and B, as being close substitutes, so that they have almost the same value of 24 or 25 for each, and they gain no extra value from winning both. For Camel the two items are pure complements with no stand-alone value for either individually but a large synergy of 25 from winning both.

With straightforward bidding of these values, the highest total value of 50 and auction efficiency is achieved, with Dolphin winning A and Elephant winning B. However, the Vickrey price for both is zero, even though the losing bidder, Camel, bid 25 for A and B. We can see this zero price from either of the ways to derive the Vickrey prices, taking Dolphin's price as an example:

Figure B2.1. Simple example of values with substitutes and complements

	Items bid for		
Bidders	Item A	Item B	Package of A and B
Camel	0	0	25
Dolphin	**25**	24	25
Elephant	24	**25**	25

Source: Author.
Note: The optimal winners of the items for auction efficiency are highlighted.

- The lowest bid Dolphin could make before failing to win item A is zero, given that Elephant makes a bid of 25 for B which is the same as Camel's bid for the package of A plus B.
- The Vickrey discount is 25 (the total bid value with Dolphin of 50 less the total value without it of 25). So Dolphin's winning bid of 25 less this discount is zero.

The example illustrates the potential problem of low revenue with Vickrey prices, which could be exploited by bidder collusion, or by 'shill' bidding where Dolphin and Elephant are really only one company but pretended in the auction to be two different bidders. The existence of large synergies for Camel means that a losing bidder placed bids in the auction that are higher than the Vickrey prices to be paid by the winners (or more generally, it could be a coalition of losing bidders that placed the higher bids). If so, the prices lie outside the 'core', the set of outcomes that involve no coalitions preferring an alternative (see Section 3.2).

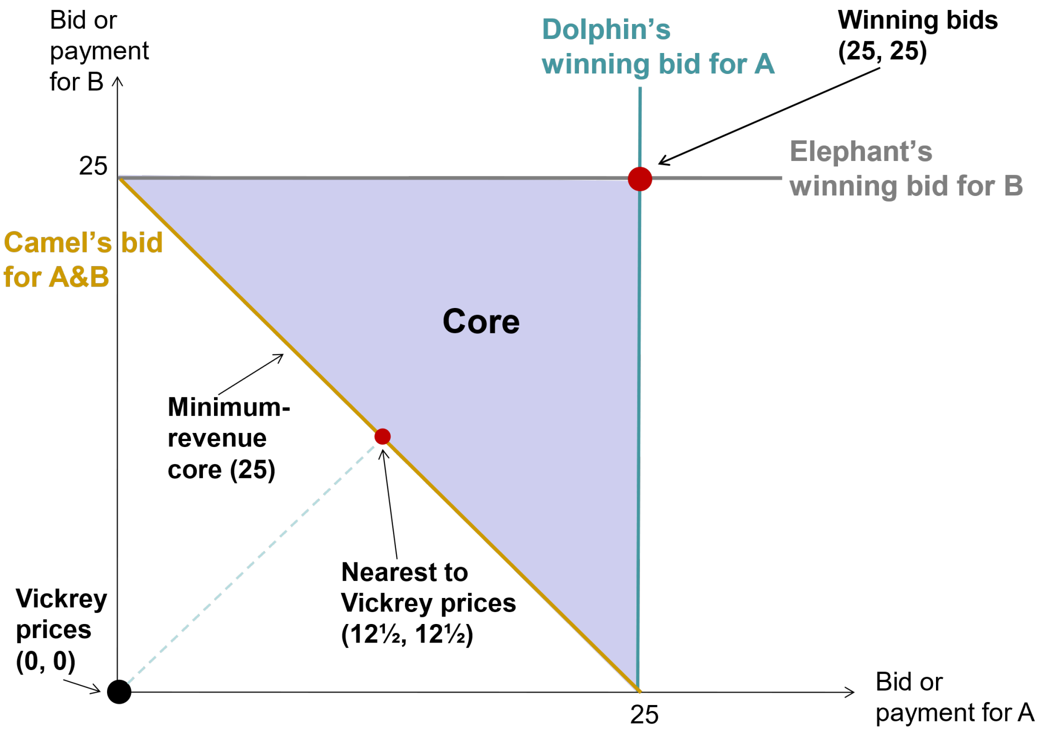
Core prices: collective opportunity cost

Some of the disadvantages of Vickrey auctions are alleviated by a modified second-price rule, requiring prices to have the following features:

- Prices lie inside the core, so that no losing bidder expressed through its bids that it was willing to pay more than the auction price for items won by others.[7]
- They represent the lowest prices in the core – minimum-revenue or 'bidder optimal' core prices.[8] The reason for this label is that the pricing rule makes bidders as well off as possible given their bids, while keeping prices above the level that losing bidders were willing to pay.
- Since the minimum-revenue core can include many sets of prices which are consistent with the winning packages and higher than the losing bids, a 'reference rule' is needed to determine which is used.[9] Although many are possible in principle, the reference rule that has been used in practice in the UK and elsewhere is 'nearest-to-Vickrey' prices.[10]

Figure B2.2 illustrates these features for the simple example. The core is the triangular shaded area bounded by each of the winning bids of Dolphin and Elephant, and the highest losing bid by Camel. The minimum-revenue core of 25 is shown as the set of prices on the line forming the bottom diagonal edge of the triangle (reflecting Camel's bid). The Vickrey prices of (0, 0) lie outside the core due to synergies in Camel's bid. The prices that are nearest to Vickrey prices in the minimum-revenue core are (12½, 12½). There is also a large gap between the winning bids of (25,25) and the auction prices of (12½, 12½).

Figure B2.2. Simple example of core and Vickrey prices



Source: Author.

Minimum-revenue core prices reflect the collective opportunity cost of allocating all the winning packages to the set of winners (which in the example is 25, the highest losing bid by Camel). Core prices have advantages of stability and fairness, because they were not outbid by any losing bidder or coalition of losing bidders. If revenue-raising is an objective, core prices can also avoid the very low revenue sometimes associated with Vickrey prices. But in principle at least, core prices can also weaken the incentives for straightforward bidding, because it is now theoretically possible for a winning bidder to affect the price it pays through its own bids. However, in practice it may be very difficult to identify how to do this successfully, and it is usually not a risk-free strategy.[11]

In the example, the Vickrey prices are outside the core, which has been the case in some North American auctions.[12] However, it is quite possible that they lie within the core and, if so, they form the unique, minimum-revenue core prices. In practice, Vickrey prices have been in the core in all UK auctions up to 2021 which have used the core pricing rule for either assignment stages or the principal stage in the CCA format.

Practical experience setting prices

An example of a *principal stage* price in the 2013 auction is for BT, which won a package of three lots of 2.6 GHz paired and four lots of 2.6 GHz unpaired (3xC plus 4xE). In the absence of BT's bids, the spectrum in its winning package would have been won by other winning bidders increasing the sizes of their winning packages. These represented the relevant highest losing bids to determine BT's package price. The sum of these incremental bid values for increasing their winning packages was BT's price of £186 million:

- Telefónica would have won an additional 2xC at an incremental bid value of £128 million compared to its winning package.
- Vodafone would have won an additional 1xC and 4xE at an incremental bid value of £58 million.

The other way to derive this Vickrey price was BT's winning bid of £340 million less its Vickrey discount of £154 million. The Vickrey discount was derived as the value that BT brought to the auction: the total bid value in the winning combination of £5,249.5 million less the highest total bid value without BT of £5,095.5 million.

The derivation of other winners' Vickrey prices was more complicated (apart from H3G which paid the reserve price for the spectrum floor it won). In the absence of their bids, there would have been a rearrangement of packages, not just a simple increase in the size of winning packages (as applied to BT's price). An example is the relevant highest losing bids to determine Vodafone's price of £791 million for a package of spectrum in three bands: two lots of 800 MHz, four lots of 2.6 GHz paired, and five lots of 2.6 GHz unpaired. The eight components of Vodafone's Vickrey price included losing bids from all six other bidders in the auction plus the reserve prices for 800 MHz and 2.6 GHz paired spectrum.[13]

Assignment stage prices are usually simpler to derive than principal stage prices, with practical examples set out in Annex A. In the assignment stage, each bidder can only win a single frequency location in each band, such as top, middle, or bottom of the band. The stakes are also lower because the values of different frequency locations are usually a modest fraction of the values of the spectrum (although there are exceptions). The practical bottom line is that, regardless of the intricacies of the underlying theory and its implementation, assignment stages with this format and pricing rule seem to work well.[14]

B3 Activity rules

CCA activity rules apply to bids in both the clock stage and the supplementary bids round (see Section 8.4). As an example I explain the rules which the regulator decided to apply in the 2013 auction, illustrated using some of the bids in 2013. I also outline other possible activity rules which have been deployed elsewhere, such as in Ireland's CCA auctions.[15]

Non-increasing demand in the clock stage as prices rise

The first element of the activity rules in 2013 prevented a bidder from increasing its quantity demanded as prices rose in the clock stage of the auction (similar to the activity rule generally used in SMRAs). This rule was intended to encourage the operator to bid more straightforwardly in early rounds and not to hide its demand. It applied during the clock stage using eligibility points set by the regulator for spectrum in different frequency bands. Each operator had to decide its initial number of eligibility points at the start of the auction (and pay a deposit to the regulator accordingly at £1,000 per eligibility point). The operator's eligibility points could not increase during the auction, but only decrease *monotonically* (i.e. either stay the same or fall) in line with the quantities of spectrum it bid for in each round. For example, in clock round 16, EE switched some of its demand from 800 MHz to the 2.6 GHz band with much lower associated eligibility than its package in round 15 (see Figure B1.1), which resulted in an irreversible reduction in its eligibility (from 9,600 to 5,400 points).

However, the monotonic eligibility rule can provide incentives for an operator to depart from straightforward bidding so as to preserve its eligibility – by bidding on larger packages with more eligibility points it could gain greater flexibility in future rounds, as probably happened in 2013. A rule that could be added to alleviate this incentive, but was not applied in 2013, is the '*relaxed activity*' rule, which permits an operator to bid for a package in the clock stage with more eligibility points than its current level in specified circumstances (where it is consistent with revealed preference, whose meaning is discussed in the next subsection).[16]

Relative cap in the supplementary bids round: consistency with revealed preference

The second element of the 2013 activity rules linked bids in the clock stage and the supplementary bids round in order to encourage straightforward bidding throughout the auction.[17] The operator's supplementary bid for its package in the final clock round was uncapped, so that it could increase the bid amount as high as it wished in the supplementary bids round. For example, Telefónica bid £890 million in the final clock round for a package comprising the 800 MHz coverage obligation lot (A2) and one lot in category D2 (which was for concurrent low-power licences for a portion of the 2.6 GHz paired spectrum), and in its supplementary bids Telefónica increased the bid amount for this package by 40 per cent up to £1,263 million.

However, the 'relative cap' activity rule then placed a limit on a firm's bid amounts for both smaller and larger packages relative to its supplementary bid for the final clock package:[18]

$$C = B + (RP - P)$$

where:

C was the cap on the supplementary bid;
B was the supplementary bid on the constraining package; and
(RP-P) was the difference in clock round prices between the package and the constraining package in the final clock round (for smaller packages), or in the round when eligibility was dropped below the eligibility for the package (for larger packages).

The bid for a *smaller* package was capped relative to the supplementary round bid on its final clock package, with the permitted differential taking account of prices in the final clock round. For example, Telefónica's winning bid in 2013 was £1,219 million for a package just containing the 800 MHz coverage obligation lot, A2. This was a smaller package than its final clock package of A2 plus one lot of D2. The relevant difference in clock round prices was the price of a D2 lot of £44 million in the final clock round, since one D2 lot was the difference in spectrum between the packages. So the relative cap on Telefónica's winning bid for the A2 lot was the supplementary bid for the final clock package £1,263 million less £44 million, or £1,219 million. Telefónica chose to make a bid on its winning package up to the maximum permitted by this relative cap.

Figure B3.1. Example of EE's revealed preference for larger and smaller packages (including A1, A2, and C) from clock stage bids in rounds 15 and 16 in 2013, and consequent relative cap constraint on its supplementary bids

Indicators	A1	A2	C	Package bid amount at prices in: Clock round when bid was made	Clock round 16	Supplementary bids for packages
Round 15: – Number of lots – Clock prices per lot	2 £301m	1 £500m	4 £29.9m	£1,222m	(RP) £1,283m	£1,652m
Round 16: – Number of lots – Clock prices per lot	0 £316m	1 £525m	6 £31.4m	£713m	(P) £713m	£1,264m
Relative cap constraint (RP–P), and difference between EE's supplementary bids					£569m	£388m

Source: Author from Ofcom auction documents.
Note: Bid amounts are shown rounded to the nearest £ million.

The bid for a *larger* package was capped relative to the supplementary round bid on the 'constraining package', which was the one that the operator bid for in the latest clock round when it had sufficient eligibility to bid on the larger package, but chose instead to bid for the constraining package (and so dropped its eligibility below the level of the larger package). The permitted differential in supplementary bids between the larger package and the constraining package reflected the clock prices in the round when eligibility was dropped. The purpose of the relative cap was for bids to be in accordance with *revealed preference* as indicated when the bidder dropped its eligibility in the clock stage by switching demand from one band to another. For example, as noted above, in round 16 EE chose to switch part of its demand from the 800 MHz band to 2.6 GHz paired. This revealed a preference at the relative prices in round 16, as set out in Figure B3.1.

EE's round 15 bid was for a larger package with 9,600 eligibility points, and its round 16 package was the smaller, constraining package at 5,400 eligibility points. EE's revealed preference by bidding for a smaller package in round 16 imposed a constraint on EE's bids in the supplementary bids round through the relative cap activity rule in accordance with the formula shown above. Specifically for this example, EE's supplementary bid amount for the larger package could not exceed its bid for the smaller package by more than the relative cap amount of £569 million shown in the bottom row. This is derived in the penultimate column as the difference in package prices when both were evaluated at clock prices in round 16 (and, for comparison, the column before that shows the bid amounts when EE bid for the larger package in round 15 in the first row, and for the smaller package in round 16 in the second row). In fact, the difference between the supplementary bids in the final column which EE chose to make was comfortably less than this constraint as it was only £388 million, between £1,652 million for the larger package and £1,264 million for the smaller package.[19]

The relative cap activity rule does not necessarily provide incentives for an operator to bid on its most preferred package in each clock round, due to the implications for flexibility in supplementary bids. The regulator can impose tighter activity rules which may improve price and package discovery in the clock stage. For example, the 'final price cap' prevents an operator from making a higher supplementary bid for its final clock package than in the clock stage, and links the maximum bid amount in all supplementary bids to the operator's final clock round bid.[20] Or a full-blown revealed preference rule would require consistency with all bids made by a bidder, not just the clock rounds in which eligibility was dropped – this approach was used in Canada's 2019 auction for the 600 MHz band.[21] The absence of tighter activity rules in the UK's 2013 auction contributed to its limited price and package discovery in the clock stage, and to the outcome being entirely dependent on the supplementary bids round. However, tighter activity rules can have disadvantages as well as strengths (see Section 8.4).

Setting eligibility points

The relative eligibility points set by the regulator for lot categories affect how an operator can switch its bids between them during the clock rounds. One reason for a bidder to switch between categories as relative prices change is if it considers them to be substitute spectrum. In the UK's 2013 auction, the categories of 800 MHz with and without coverage obligation (A2 and A1 respectively) were spectrum in the same band, so they were very close substitutes. Movements in the relative prices of categories A1 and A2 provided different discounts for taking on the coverage obligation. In addition, the categories of 2.6 GHz paired and unpaired (C and E) provided alternative capacity spectrum, although before the auction it was less clear how close substitutes these two categories would be, because the technology for unpaired spectrum was little used in Europe at that time.

A second reason for a bidder to switch between categories is based on its budget. For instance, an operator may have demand for coverage spectrum (800 MHz) and capacity spectrum (2.6 GHz), but a limited budget and so be unable to acquire both. It may prioritise winning the coverage spectrum, for example, but if that becomes too expensive relative to its budget, it could switch its demand to the cheaper capacity spectrum.

Eligibility point ratios between categories are sometimes set by regulators on the basis of expected relative value, such as using the ratio of reserve prices. This was the starting point for Ofcom's choices for the 2013 auction. However, the ratio of reserve prices is often unsuitable when applied to substitute inputs as illustrated by categories A1 and A2 for the 800 MHz band.[22] Comparing the same amount of spectrum, the reserve prices for 20 MHz were £450 million for A1 and £250 million for A2, a ratio of 1.8 (the difference in reserve prices reflecting a crude estimate by the regulator of the cost of the coverage obligation attached to the A2 lot). If the eligibility points had been set using this ratio, an operator who was only bidding for 800 MHz spectrum and switched from A1 to A2 during the clock stage would have faced a reduction in its relative eligibility from 1.8 points to 1 point. It would therefore have been unable to switch back to A1 if the relative price of A2 went up, except by bidding for less spectrum, 10 MHz instead of 20 MHz with eligibility of 0.9 points. It would then have not had enough eligibility to switch again into A2, if the relative price of A1 increased.

In essence, it can be 'putting the cart before the horse' to use reserve prices to fix the eligibility points and the terms of switching between categories of closely substitutable spectrum. It is the role of the auction to set prices reflecting market value, and there can be a high risk of regulatory failure for the regulator to second-guess this process. Again, the 800 MHz band provides an illustration,

Figure B3.2. Eligibility points per 10 MHz in 2013, based on relative reserve prices except for 800 MHz spectrum with and without the coverage obligation

Category	Label	Reserve price per 10 MHz	Eligibility points per 10 MHz
800 MHz (with coverage obligation)	A2	£100m	2250
800 MHz (without coverage obligation)	A1	£225m	2250
2.6 GHz paired	C	£15m	150
2.6 GHz unpaired	E	£0.2m	2

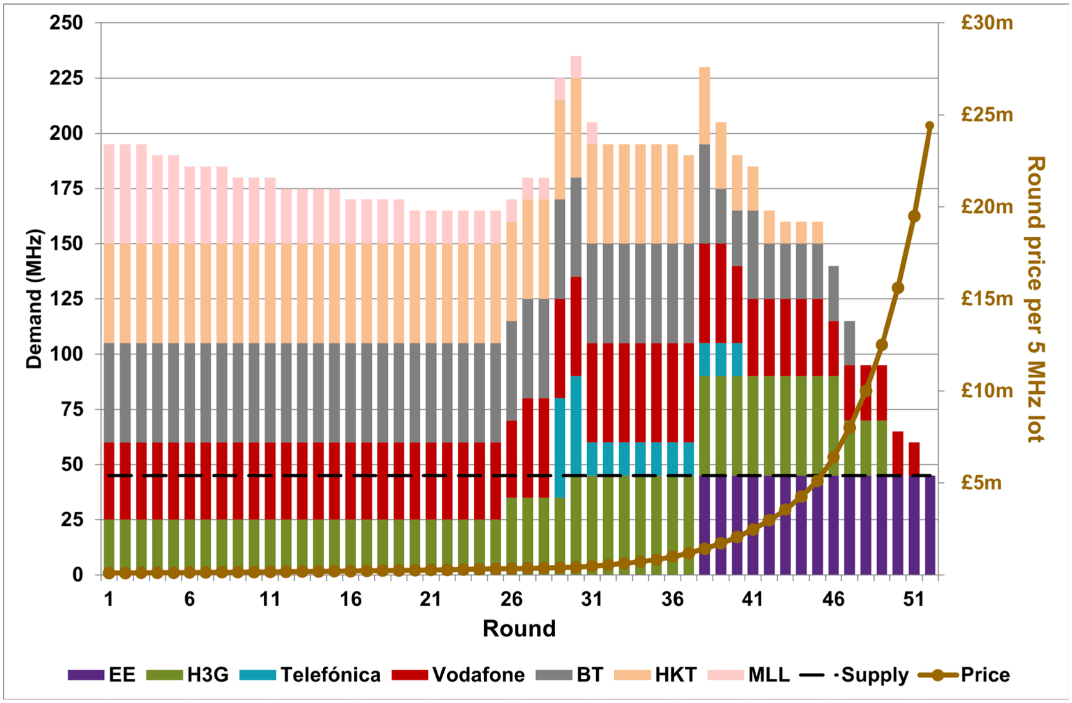
Source: Author from Tables 7.1 and 8.1 in Ofcom (2012b).

because Ofcom decided to depart from pre-auction estimates of relative value when setting these eligibility points and specified the same eligibility per MHz for A1 and A2 lots. The principle adopted here was to reflect suitable *relative amounts* of spectrum for substitute spectrum, in this case MHz for MHz between 800 MHz spectrum with and without the coverage obligation. This approach facilitated a significant amount of switching in both directions between A1 and A2 during the clock rounds, as shown in Figure B1.2 in the movement between the paler and darker colour shades for each bidder (with and without the coverage obligation). At the end of the clock stage, such switching led to the exact same price per MHz, which was extremely different from the regulator's pre-auction estimate for reserve prices.

The ability of bidders to switch in *both* directions can effectively be precluded by eligibility point choices as was the case for other bands in 2013. Ofcom set the ratios of eligibility points between the categories for 800 MHz and 2.6 GHz paired, and those for 2.6 GHz paired and unpaired, by using relative reserve prices. Figure B3.2 compares reserve prices and eligibility points for the four lot categories (all expressed per 10 MHz for ease of comparison). In the first two rows 800 MHz with and without the coverage obligation had the same eligibility points, even though their reserve prices were quite different. Comparing the second and third rows shows that the ratio of eligibility points between 800 MHz without coverage obligation and 2.6 GHz paired was the same as their ratio of reserve prices. This was also the case for 2.6 GHz paired and unpaired in the third and fourth rows.

Consequently, operators could switch from 800 MHz to 2.6 GHz paired, or from paired to unpaired 2.6 GHz, but it would involve such a large reduction in eligibility that switching back was not feasible.[23] So the regulator's choices for eligibility points contributed to one-way switching during the clock stage, and the lowest-value band, 2.6 GHz unpaired, was the last to be resolved. For example, as shown in Figure B3.3, the highest levels of demand for 2.6 GHz unpaired were in clock rounds 30 and 38, due to Telefónica, H3G, and EE switching demand into this band from other categories. However, subsequently there was no switching away by an operator from 2.6 GHz unpaired into other categories, and only demand reductions. After the clock stage, operators could still use their package bids in the supplementary bids round to express their preferences for substitute spectrum. But the limitations on switching to and from the 800 MHz, 2.6 GHz paired, and 2.6 GHz unpaired bands during the clock stage likely contributed to weak price discovery in the 2013 auction. Operators could have had greater opportunities to switch their demand between bands in 2013, if the ratios of eligibility points set by the regulator had departed from the ratios of reserve prices and instead attempted to reflect suitable relative amounts of spectrum.

Figure B3.3. Clock bids and prices in the 2.6 GHz unpaired band in 2013 (illustrating one-way switching)



Source: Author from Ofcom auction documents.

Notes

[1] In addition, category D was for concurrent low-power licences for a portion of the 2.6 GHz paired spectrum (and category B allowed for 1800 MHz spectrum that was ultimately not included in the auction). The D1 and D2 lot categories included up to 10 concurrent low-power licences for 20 MHz and 40 MHz respectively of the 2.6 GHz paired spectrum. The auction bidding determined whether this spectrum was awarded as these shared low-power licences or instead as exclusive high-power licences in category C (which was the outcome).

[2] Lower principal stage prices compared to the clock rounds reflected several factors, including subtleties in the determination of second prices in package auctions. There were 'missing bids' in the highest losing combinations to determine second prices, resulting in reserve price components in all package prices apart from BT's. In addition, there had been excess supply at the end of the clock stage in the 800 MHz and 2.6 GHz paired bands, and principal stage prices were non-linear with declining marginal prices (except over amounts reflecting synergies in losing bids).

[3] Linear reference prices are the linear prices (that is, the same per MHz) that are estimated to be closest to market-clearing prices. In the case of the 2013 auction, linear prices would have failed to clear the market due to synergies (non-linear bid values), resulting in either excess demand or excess supply in each band according to the bids made. For further details, and other methods which could be used to decompose package prices into band-specific prices, see Ofcom (2015, annex 6).

[4] Vickrey (1961).

[5] Ausubel and Milgrom (2006), and Rothkopf (2007).

[6] Marszalec (2018) shows experimental evidence consistent with collusion in Vickrey auctions.

[7] In assignment stages and the CCA principal stage, the core is with respect to the preferences reported in the auction bids. It may be different from the core reflecting true values if bids are not straightforward.

[8] Day and Milgrom (2008).

[9] Erdil and Klemperer (2010).

[10] Day and Cramton (2012).

[11] In theory, a winning bidder can reduce its price by lowering its winning bid in order to change either the core or other winners' Vickrey prices and so shift the set of prices in the minimum-revenue core that is nearest to Vickrey — see Erdil and Klemperer (2010). However, in practice the number of categories and bidders usually makes it very difficult to identify the precise bidding strategy to achieve the price reduction. Furthermore, the strategy is usually not risk-free, because it could result in the bidder winning a less preferred package, or failing to win. The risk-reward trade-off may be unfavourable and so gaming of the reference rule, although possible, is often not attractive in practice. For example, limited bid shading was observed in the experiments by Bichler, Shabalin and Wolf (2013).

[12] Ausubel and Baranov (2020a, p.252).

[13] Ofcom (2015, table A6.5).

[14] An exception may be some instances of successful coordination in the assignment stage of the forward auction in the USA's 2016–17 incentive auction, which used Vickrey pricing (not minimum-revenue core) – see Kominers and Teytelboym (2020, p.1186).

[15] For example, the relaxed activity rule during the clock stage, and the relative and final price cap rules in the supplementary bids round were all included in the design for Ireland's auction planned for 2021 (but delayed by litigation) – see ComReg (2021, paragraphs 3.205–3.209 and 3.221–3.226).

[16] Bichler and Goeree (2017, section 3.2.1).

[17] The underlying logic is that, if an operator fails to bid straightforwardly in the clock stage, it might be prevented by the activity rules from placing its preferred bids in the supplementary bids round.

[18] See Regulation 43(7) in the 2013 auction rules - The Wireless Telegraphy (Licence Award) Regulations, Statutory Instruments, 2012 No. 2817, Electronic Communications: https://perma.cc/NDS9-N7NB 🔓.

[19] Figure B3.1 provides a simplified explanation of the relative cap rule for larger packages, because if, as here, the constraining package was not the final round package, then a chain of bid restrictions applied. The supplementary bid on a larger package was capped relative to the supplementary bid on the constraining package, which in turn was capped relative to another constraining package. The chain ended when the constraining package was the final clock package.

[20] Bichler and Goeree (2017, section 3.2.2).

[21] Ausubel and Baranov (2020b).

[22] Even for budget-based switching, the suitability of eligibility points based on relative reserve prices depends on bidders having demand for a similar number of lots in each category, and also the regulator setting reserve prices in a similar fashion between the relevant bands (which was not the case in the UK's 2013 auction, as explained in Section 7.3).

[23] Ausubel and Baranov (2020b, section 7.3).

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Annex C: Additional explanation of the cost-benefit role of auctions

This annex explains more about the innovative CCA designs set out in Chapter 10, where the auction is used as part of a cost-benefit analysis of policy alternatives. The first section considers H3G's incentives when bidding for spectrum floors in the UK's 2013 auction. Then, the second section shows a worked example of the auction's cost-benefit role when it is designed to sell spectrum and procure coverage obligations simultaneously.

C1 Bids by H3G for spectrum floors in the UK's 2013 auction

In 2013 the difference of £165 million between H3G's bid amounts for alternative spectrum floors provided the benefit side of the cost-benefit analysis conducted within the auction to determine the choice of reserved spectrum, and the cost side was the opportunity cost of £107 million reflected in the bids of all the other operators (see Section 10.1). H3G seemed to design its bid strategy to ensure that whichever spectrum floor it obtained would be at the reserve price, and it won the floor of one lot of 800 MHz spectrum without coverage obligation (1xA1) at a reserve price of £225 million.[1] Did the 2013 auction determine the economically efficient choice of spectrum floors, given H3G's strategic bids?

Section 10.1 suggested that H3G would have been risking a loss in profit by departing in its bids from the difference in its intrinsic values. To analyse this profit loss in more detail, assume, as shown in the final column of the third row in Figure C1.1 that H3G's incremental intrinsic value was only £50 million – the difference between intrinsic values of £250 million for the floor of 1xA1 and £200 million for the other floor of four lots in the 2.6 GHz paired band (4xC). Under this assumption, the economically inefficient choice of spectrum floor would have been made in the 2013 auction, because the assumed incremental *intrinsic* value was less not more than the opportunity cost to other bidders of £107 million. However, such a low incremental intrinsic value and the wrong choice of spectrum floor is not easy to reconcile with H3G's *observed* bids, because it would have made H3G's observed incremental bid value of £165 million significantly less profitable.

The first column in Figure C1.1 shows the outcome for an incremental bid value reflecting *strategic* bids of the difference in reserve prices of £165 million, consistent with H3G's observed bids. At the assumed intrinsic value of £250 million, it would earn an illustrative profit of £25 million. However, if H3G's true values had been similar to these illustrative assumptions for intrinsic values, it would instead have been much more profitable to make straightforward bids, as shown in the second column.

With straightforward bidding of the assumed incremental *intrinsic* value of £50 million, H3G would have won the other spectrum floor, 4xC, because that incremental bid value would have been less not more than the opportunity cost to other bidders. H3G would have paid a price well above the reserve price of £60 million at £118 million (calculated as the £225 million reserve price for the other floor, 1xA1, less the opportunity cost to other bidders of £107 million).[2] However, even with the price

Figure C1.1. Comparison of strategic and straightforward bids for spectrum floors for illustrative assumed intrinsic values in £ million

	Strategic bids reflecting difference in reserve prices	Straightforward bids reflecting assumed intrinsic values
Floor of 1xA1	225	250
Floor of 4xC	60	200
Incremental bid value	165	50
Opportunity cost to other bidders for 1xA1 over 4xC	107	
Winning floor	1xA1	4xC
Price	225	118
Profit	25	82

Source: Author.

above the reserve level, the straightforward bid strategy would have been much more profitable at £82 million (the assumed £200 million intrinsic value for 4xC less the price of £118 million).

The loss of profit from strategic instead of straightforward bidding would have been £57 million (£82 million with straightforward bidding less £25 million with the strategic bids), caused by strategic bidding leading to the inefficient choice of spectrum floor. When that occurred, the loss of profit was equal to the opportunity cost of £107 million less H3G's assumed incremental intrinsic value of £50 million, and it would therefore have increased, the more that the observed incremental *strategic* bid value of £165 million departed from the incremental *intrinsic* value. This loss of profit tends to reduce the likelihood of a low incremental intrinsic value for H3G as in the illustrative assumptions, compared to an amount above the opportunity cost of £107 million and closer to H3G's observed incremental bid value – for which the outcome in the auction of 1xA1 as the winning floor would have been the economically efficient choice.

C2 Unbundled coverage obligations

In 2018 the UK regulator proposed to integrate the procurement of coverage obligations into a CCA design which would also simultaneously sell spectrum by using unbundled coverage obligations offered in the auction at negative prices (see Section 10.2). I provide here a simple worked example of the cost-benefit role of the auction for a single obligation. The same principles would apply to multiple obligations, and to multiple levels of an obligation.

The role given to cost-benefit analysis when determining the auction outcomes means that a bid for a coverage obligation wins only if the level of benefits specified by the regulator is at least as high as the costs indicated by auction bids. In this approach the regulator uses its policy judgement to estimate the benefits – the social and public value of the extended mobile coverage provided by a coverage obligation – and sets the negative reserve price of the unbundled obligation at this level. A negative reserve price provides a maximum subsidy to an operator taking on an obligation or the maximum discount available to offset its spectrum purchases.

The costs of an obligation to the firms bidding are measured in the auction by the loss in total bid value if an obligation is awarded. There are two categories of cost:

Figure C2.1. Illustrative bids for spectrum and a coverage obligation – first scenario where the coverage obligation is awarded

Comparing two sets of bids: (i) and (ii)	700 MHz lots	3.6–3.8 GHz lots	Coverage obligation	Bid amounts
Flamingo, without obligation (i)	3	12	0	1000
Giraffe, without obligation (i)	3	12	0	600
Total bid value without obligation (i)	6	24	0	1600
Flamingo, with obligation (ii)	3	16	1	800
Giraffe, without obligation (ii)	3	8	0	500
Total bid value with obligation: (ii)	6	24	1	1300
		Loss in total bid value (**LTBV**)		300
Maximum discount (MD = 350) versus LTBV (previous row)		Award the obligation: because set (ii) wins		MD > LTBV

Source: Author.

- Network cost – the difference in bids by the coverage bidder for the same spectrum with and without the obligation.
- Opportunity cost of a change in the allocation of spectrum – the difference between the incremental bid values of the coverage bidder gaining, and other firms losing, the additional spectrum whose allocation is changed.

Figure C2.1 illustrates how package bids from the supplementary bids round can lead to the obligation being awarded in a first scenario. Two sets of bids are shown, labelled (i) and (ii), made by two bidders, called Flamingo and Giraffe. For illustration, the spectrum lots are the two main bands in the 2021 auction, 700 MHz and 3.6–3.8 GHz. The first set of bids, (i), in the first two rows is the highest-value combination of package bids from the two bidders for all the spectrum lots but without a bid for the coverage obligation. Both make bids for 3 lots of 700 MHz and 12 lots of 3.6–3.8 GHz at differing bid amounts, 1000 by Flamingo and 600 by Giraffe. Hence, the total value of this set of bids in the third row is 1600.

The second set of bids, (ii), in the fourth and fifth rows is the highest-value combination of package bids from the two bidders for all the spectrum lots, but this time including a bid for the coverage obligation by Flamingo. Flamingo's package now includes more spectrum, 16 instead of 12 lots of 3.6–3.8 GHz, alongside the obligation. Giraffe's package is correspondingly smaller with 8 instead of 12 lots of 3.6–3.8 GHz and no coverage bid. In other words, in this example the spectrum allocation would be changed by the coverage obligation being awarded – Flamingo would win 4 more lots of 3.6–3.8 GHz and Giraffe 4 fewer lots. The bid amounts are also different compared to set (i). Although Flamingo's spectrum package is larger than in set (i) it specifies a lower bid amount by 200 (at 800 instead of 1000), because its cost of the obligation is assumed here to be bigger than its value for the additional spectrum.[3] Giraffe's package is smaller and so its bid amount is lower by 100 (at 500 instead of 600). The total value of the second set of bids in the sixth row is 1300.

To determine whether the bid for the coverage obligation is a winning bid, we look at the difference in total bid value compared to the maximum discount which is assumed to be 350. The loss in bid value in set (ii) compared to set (i) is 300 in the seventh row, reflecting both categories of cost

Figure C2.2. Illustrative bids for spectrum and a coverage obligation – second scenario where the coverage obligation is not awarded

Comparing two sets of bids: (i) and (ii)	700 MHz lots	3.6–3.8 GHz lots	Coverage obligation	Bid amounts
Flamingo, without obligation (i)	3	12	0	1000
Giraffe without obligation (i)	3	12	0	700
Total bid value without obligation (i)	6	24	0	1700
Flamingo, with obligation (ii)	3	16	1	800
Giraffe with obligation (ii)	3	8	0	500
Total bid value with obligation (ii)	6	24	1	1300
			LTBV	400
Maximum discount (MD = 350) versus LTBV (previous row)	Do not award the obligation: because set (i) wins			MD < LTBV

Source: Author.

(network and opportunity cost), which is less than the maximum discount as shown in the bottom row. So the cost-benefit balance is favourable and the obligation is awarded.

Figure C2.2 shows a second scenario, with higher opportunity costs of the change in allocation and where the coverage obligation is not awarded. Giraffe's reduction in bid amount between the first set of bids (700) and the second set (500) is now higher at 200 instead of 100 in the first scenario, reflecting its higher opportunity cost of losing out on the 4 lots of 3.6–3.8 GHz. This means that the total costs of awarding the coverage obligation are also larger by 100, so that in this scenario the costs exceed the benefits given by the maximum discount. Even though Flamingo makes a bid for the coverage obligation, it is not a winning bid because the cost-benefit balance is unfavourable.

Notes

1. Myers (2013).
2. See Myers (2013, p.20) for an explanation of the pricing rule for spectrum floors.
3. The difference of 200 between Flamingo's bid amounts is smaller than its network cost of the obligation by its value for the additional spectrum (4 lots of 3.6–3.8 GHz). Flamingo's network cost would be transparent if it also made a bid for the coverage obligation with the same number of 700 MHz and 3.6–3.8 GHz lots as in the first set of bids. The net opportunity cost of a change in spectrum allocation is the difference between Flamingo's incremental bid value to gain the additional lots and Giraffe's higher loss in incremental bid value by losing out on them, which would be the residual between the loss in total bid value of 300 and that network cost.

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