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.

References

Note: means an open access publication.

Binmore, Ken and Klemperer, Paul (2002) 'The Biggest Auction Ever: The Sale of the British 3G Telecom Licences', *Economic Journal*, vol. 112, no. 478, pp.C74–96. https://doi.org/10.1111/1468-0297.00020

Coase, Ronald (1959) 'The Federal Communications Commission', *Journal of Law and Economics*, vol. 2, pp.1–40. http://doi.org/10.1086/466549

Coase, Ronald (1998) 'Comment on Thomas W. Hazlett: Assigning Property Rights to Radio Spectrum Users: Why Did FCC License Auctions Take 67 Years?', *Journal of Law and Economics*, vol. 41, S2, pp.577–80. https://doi.org/10.1086/467402

GSMA (2021b) 'The State of Mobile Internet Connectivity 2021'. https://perma.cc/FK7S-BA5M

GSMA (2021c) 'The Climate Crisis: Mobile-enabled solutions in humanitarian emergencies'. https://perma.cc/P2KD-BVP4

GSMA (2022) 'State of the Industry Report on Mobile Money 2022'. https://perma.cc/3X5R-TUFZ

Herzel, Leo (1951) '"Public Interest" and the Market in Color Television Regulation', *University of Chicago Law Review*, vol. 18, no. 4, pp.802–16. https://doi.org/10.2307/1598016

Koutroumpis, Pantelis and Cave, Martin (2018) 'Auction Design and Auction Outcomes', *Journal of Regulatory Economics*, vol. 53, no. 3, pp.275–97. https://doi.org/10.1007/s11149-018-9358-x

Ofcom (2021b) 'Online Nation', 2021 report, 9 June. https://perma.cc/BU47-LXND

Samsung (2022) '6G Spectrum: Expanding the Frontier', May. https://perma.cc/387T-Q28M