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

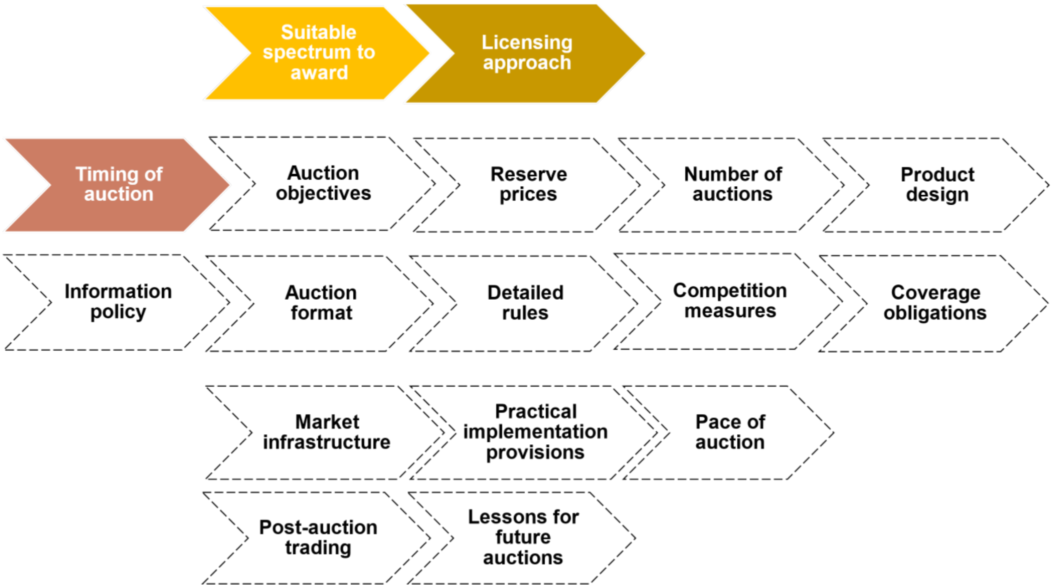
Summary

- 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.

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

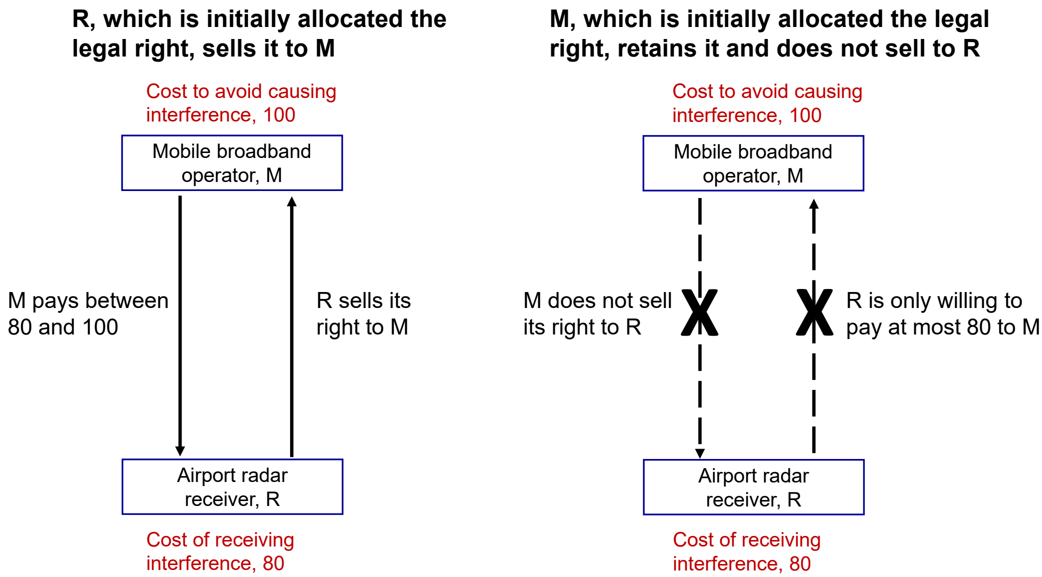
Spectrum is a natural resource, classified in economic terms as a common pool resource. Without regulation, it is *rival* in use, since the radio transmissions of one user generally cause harmful interference for other users who are nearby in location or frequency. Therefore, apart from frequencies that 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.

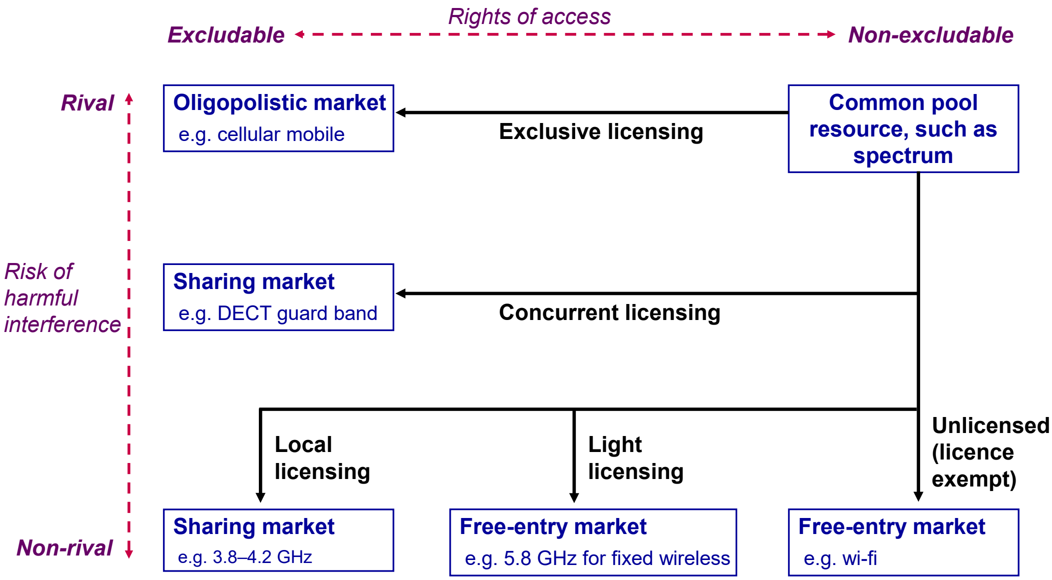
Spectrum licence choices implying different types of market

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).

References

Note: 🔓 means an open access publication.

Arrow, Kenneth; Cropper, Maureen; Eads, George; Hahn, Robert; Lave, Lester; Noll, Roger; Portney, Paul; Russell, Milton; Schmalensee, Richard; Smith, Kerry; and Stavins, Robert (1996) 'Is There a Role for Benefit-Cost Analysis in Environmental, Health, and Safety Regulation?', *Science*, vol. 272, 5259, pp.221–22. https://doi.org/10.1126/science.272.5259.221

Brake, Doug (2015) 'Coase and WiFi: The Law and Economics of Unlicensed Spectrum', *The Information Technology and Innovation Foundation*, January. https://perma.cc/98LJ-7ZC2 🔓

Carrigan, Christopher and Shapiro, Stuart (2017) 'What's Wrong with the Back of the Envelope?', *Regulation & Governance*, vol. 11, no. 2, pp.203–12. https://doi.org/10.1111/rego.12120

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 (1960) 'The Problem of Social Cost', *Journal of Law and Economics*, vol. 3, pp.1–44. http://doi.org/10.1057/9780230523210_6

Cramton, Peter; Kwerel, Evan; and Williams, John (1998) 'Efficient Relocation of Spectrum Incumbents', *Journal of Law and Economics*, vol. 41, S2, pp.647–76. https://doi.org/10.1086/467407

Department for Communities and Local Government (2009) 'Multi-criteria analysis: a manual'. https://perma.cc/M9GZ-NUV4 🔓

Frischmann, Brett; Marciano, Alain; and Ramello, Giovanni Battista (2019) 'Tragedy of the Commons after 50 Years', Retrospectives, *Journal of Economic Perspectives*, vol. 33, no. 4, pp.211–28. https://doi.org/10.1257/jep.33.4.211 🔓

Goeree, Jacob; Palmer, Karen; Holt, Charles; Shobe, William; and Burtraw, Dallas (2010) 'An Experimental Study of Auctions versus Grandfathering to Assign Pollution Permits', *Journal of the European Economic Association*, vol. 8, nos. 2/3, pp.514–25. https://doi.org/10.1111/j.1542-4774.2010.tb00522.x

Hansson, Sven Ove (2010) 'Cost–Benefit Analysis: Philosophical Issues', in *The New Palgrave Dictionary of Economics*, London: Palgrave Macmillan. https://doi.org/10.1057/978-1-349-95121-5_2918-1 🔓

Hardin, Garrett (1968) 'The Tragedy of the Commons', *Science*, vol. 162, 3859, pp.1243–48. https://doi.org/10.1126/science.162.3859.1243

Hazlett, Thomas and Leo, Evan (2011) 'The Case for Liberal Spectrum Licenses: A Technical and Economic Perspective', *Berkeley Technology Law Journal*, vol. 26, no. 2, pp.1037–1102 (Article 4). https://doi.org/10.15779/Z387X2H 🔓

Hazlett, Thomas and Muñoz, Roberto (2009a) 'A Welfare Analysis of Spectrum Allocation Policies', *RAND Journal of Economics*, vol. 40, no. 3, pp.424–54. https://doi.org/10.1111/j.1756-2171.2009.00072.x

Hazlett, Thomas and Muňoz, Roberto (2009b) 'Spectrum Allocation in Latin America: An Economic Analysis', *Information Economics and Policy*, vol. 21, no. 4, pp.261–78. https://doi.org/10.1016/j.infoecopol.2009.05.00

HM Treasury (2020) 'The Green Book', Central government guidance on appraisal and evaluation. https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent/the-green-book-2020

Kwerel, Evan; Sanyal, Paroma; Seim, Katja; Stancill, Martha; and Sun, Patrick (2017) 'Economics at the FCC, 2016–2017: Auction Designs for Spectrum Repurposing and Universal Service Subsidies', *Review of Industrial Organization*, vol. 51, no. 4, pp.451–86. https://doi.org/10.1007/s11151-017-9597-5

Lewis, Charley (2018) 'Lessons From Spectrum Auctions: A Benchmark Approach'. https://ssrn.com/abstract=3185752

Leyton-Brown, Kevin; Milgrom, Paul; and Segal, Ilya (2017) 'Economics and computer science of a radio spectrum reallocation', *Proceedings of the National Academy of Sciences*, vol. 114, no. 28, pp.7202–09. https://doi.org/10.1073/pnas.1701997114

McCubbins, Matthew; Noll, Roger; and Weingast, Barry (1987) 'Administrative Procedures as Instruments of Political Control', *Journal of Law, Economics, & Organization*, vol. 3, no. 2, pp.243–77. https://www.jstor.org/stable/764829

Medema, Steven (2020) 'The Coase Theorem at Sixty', *Journal of Economic Literature*, vol. 58, no. 4, pp.1045–1128. https://doi.org/10.1257/jel.20191060

Milgrom, Paul (2004) *Putting Auction Theory to Work*, Cambridge: Cambridge University Press.

Milgrom, Paul; Weyl, Glen; and Zhang, Anthony Lee (2017) 'Redesigning Spectrum Licenses', *Regulation*, vol. 40, no. 3, pp.22–26. https://perma.cc/V7X6-V6FK

OECD (2022) 'Developments in spectrum management for communication services', *OECD Digital Economy Papers*, no. 332, Paris: OECD Publishing. https://doi.org/10.1787/175e7ce5-en

Ofcom (2014c) 'Decision to make the 700 MHz band available for mobile data', Statement, 19 November. https://perma.cc/ZNZ8-RVZY

Ofcom (2015) 'Annual licence fees for 900 MHz and 1800 MHz spectrum', Statement, 24 September. https://perma.cc/77U4-AADM, https://perma.cc/BW4F-PTCC https://perma.cc/XV6E-3694, https://perma.cc/UD5F-HDLV

Ofcom (2019) 'Enabling wireless innovation through local licensing: Shared access to spectrum supporting mobile technology', Statement, 25 July. https://perma.cc/FP58-W3D7.

Ofcom (2020c) 'The Communications Market 2020', 30 September. https://perma.cc/JQ98-TFWU

Ofcom (2020f) 'Supporting the UK's wireless future: Our spectrum management strategy for the 2020s', Consultation, 4 December. https://perma.cc/7GP5-DTCC

Ofcom (2021a) 'The Office of Communications Annual Report and Accounts for the period 1 April 2020 to 31 March 2021', HC459. https://perma.cc/PY4Y-D3J3

Ofcom (2022) ‘Enabling mmWave spectrum for new uses: Making the 26 GHz and 40 GHz bands available for mobile technology’, Consultation, 9 May. https://perma.cc/72J6-254Z

Ostrom, Elinor (2008) ‘Tragedy of the Commons’ in *The New Palgrave Dictionary of Economics*, London: Palgrave Macmillan. https://doi.org/10.1057/978-1-349-95121-5_2047-1

Rose-Ackerman, Susan (2011) ‘Putting Cost-Benefit Analysis in its Place: Rethinking Regulatory Review’, *University of Miami Law Review*, vol. 65, no. 2, pp.335–56. https://repository.law.miami.edu/umlr/vol65/iss2/3

Rosston, Gregory and Skrzypacz, Andrzej (2021) ‘Reclaiming spectrum from incumbents in inefficiently allocated bands: Transaction costs, competition, and flexibility’, *Telecommunications Policy*, vol. 45, no. 7, article 102167. https://doi.org/10.1016/j.telpol.2021.102167

Self, Peter (1975) *Econocrats and the Policy Process: The Politics and Philosophy of Cost-Benefit Analysis*, London: Red Globe Press. https://doi.org/10.1007/978-1-349-86169-9

Shapiro, Fred and Pearse, Michelle (2012) ‘The Most-Cited Law Review Articles of All Time’, *Michigan Law Review*, vol. 110, no. 8, pp.1483–520. https://repository.law.umich.edu/mlr/vol110/iss8/2

Stavins, Robert (2011) ‘The Problem of the Commons: Still Unsettled after 100 Years’, *American Economic Review*, vol. 101, no. 1, pp.81–108. https://doi.org/10.1257/aer.101.1.81

Weimer, David (2008) ‘Cost–Benefit Analysis’, in *The New Palgrave Dictionary of Economics*, London: Palgrave Macmillan. https://doi.org/10.1057/978-1-349-95121-5_381-2

Weyl, Glen and Zhang, Anthony Lee (2022) ‘Depreciating Licences’, *American Economic Journal: Economic Policy*, vol. 14, no. 3, pp.422-48. https://doi.org/10.1257/pol.20200426