dot·econ

Collecting revenue from spectrum

A report for GSMA

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Spectrum has a substantial economic value. Telecommunications services derived from spectrum are purchased not just directly by customers, but also form a key input into nearly every sector of a modern economy. Therefore, it is essential that governments have appropriate objectives when allocating spectrum in order to realise these benefits for their citizens.

In practice, there is significant variation in the objectives adopted by spectrum authorities. In the EC, regulators must work within the constraints of European law that set efficient allocation as the predominant objective. Other jurisdictions have emphasised revenue maximisation (e.g. in the Indian Government in the 2010 3G auction) subject to maintaining effective downstream competition in providing mobile services.

Efficient allocation is an appropriate objective

Efficient allocation of spectrum means placing spectrum in the hands of those able to create greatest overall benefit from it. Provided that competition between spectrum licensees in providing telecoms services is effective, efficient allocation can usually be achieved by licensing spectrum to whoever values it most. As a result, auctions can provide a useful tool to achieve efficient allocation, which may also generate very significant sums for the public purse as a by-product.

There are strong arguments that efficient allocation should be the overriding objective for spectrum allocation. Given the importance of services derived from spectrum for the wider economy, governments are typically best served by seeking to maximise the *overall* benefit to society from spectrum, rather than simply maximising receipts from spectrum sales in the short-run.

Revenue maximisation should protect downstream competition

Nevertheless, where a government pursues a revenue objective – rather than one of efficient allocation – it must ensure that downstream competition providing in spectrum-derived services to end-users remains effective.

Greatest overall revenue would be achieved by allowing concentration of spectrum held in order to weaken downstream competition – in the worst case creating a monopoly in services – with the profit so generated extracted through competition for spectrum. However, such revenue would come at the expense of consumers and effective long-run use of spectrum would be undermined by lack of competition amongst operators

Efficient allocation and revenue maximisation are often largely aligned

Providing measures are taken to promote effective downstream, the objectives of revenue maximization and efficient allocation of spectrum are largely aligned. In particular, efficient allocation of spectrum requires that licensees pay the opportunity cost of the spectrum they are awarded; in turn this entails raising *some* revenue as a by-product of efficient allocation. Ensuring that spectrum goes to whoever values it most is broadly compatible with obtaining the greatest revenue; indeed if spectrum did not go to high-value users, then revenue could not be maximized.

Provided downstream competition is not compromised, spectrum auctions can be a relative distortion-free source of funds for governments, avoiding much of the distortions associated with raising general taxation.

Common features needed for efficiency and revenue

There are many features of good practice in spectrum allocation that promote *both* efficient allocation *and* revenue:

- spectrum licences need to have clear rights and obligations;
- spectrum authorities acting in a predictable manner, keeping to previously made commitments and avoiding 'hold-up';
- competition for spectrum should be maximised by providing as much flexibility as possible for bidders to bid for what they want, subject to the need to protect downstream competition.

These features encourage auction participation, which in turn is important for creating effective competition for spectrum and greatly facilitates a successful auction.

Even where the field of bidders may be limited (for example to existing operators) competition for spectrum may still be vigorous is there is flexibility in the amount of spectrum that may be acquired by each bidder. This contrasts with using monolithic spectrum packaging where each licensee wins an identical quantity of spectrum pre-packaged as a single lot. Some recent auctions (using combinatorial formats) have seen significant competition for spectrum even where only incumbent operators are bidding as a result of competition amongst these bidders over the amount of spectrum they win.

Maximising revenue where competition for spectrum is weak

In certain cases where competition for spectrum is weak (even after taking steps to encourage participation and competition amongst bidders), it may be possible to 'tweak' an auction to raise somewhat more revenue than if efficiency were the sole goal. Value can be extracted from strong bidders by confronting them with a risk of not winning unless they raise the amount they pay. Regardless of how exactly a greater competitive challenge for strong bidders is achieved through the detailed auction rules, a small amount of efficiency is sacrificed for a gain in revenue.

Where such approaches are adopted to boost revenue in situations of weak competition for spectrum, they need to be adopted with considerable care. In particular, if too much efficiency is lost, then revenue will be compromised as well. Such 'tweaks' need to modify the behaviour of strong bidders by creating a challenge that they will not win, yet not create such a role for chance that the strongest bidders fail to win with high probability, otherwise revenue will not be maximised.

Therefore, we should be cautious about significant deviations from standard auction methodologies that claim to be able to create much more revenue unless they are carefully analysed and tested. There are examples where auctions have failed due to the unanticipated impact of their rules on the incentives of bidders (e.g. the Turkish GSM auction).

1 Introduction

In this paper, commissioned by the GSM Association, we consider the role of spectrum auctions in generating revenues for governments. Auctions can raise sums that are large enough to have an effect on public finances. Should we be concerned that governments might adopt counterproductive approaches that fail to make best use of spectrum in the long term simply to raise more money in the short term?

Auctions provide a means of allocating scarce spectrum to those best able to extract value from it. They have become an essential tool for spectrum regulators as they avoid the difficulties associated with 'beauty parades' where administrative decisions have to be made about who is best placed to use spectrum, often on the basis of highly inadequate information and with no means to verify the claims made by applicants. In contrast, well-designed auctions can provide spectrum regulators with a means of ensuring that spectrum is efficiently used, ending up in the hands of those best able to use it.

In Section 2, we discuss the idea of *efficient allocation* and consider this objective relative to an objective of *revenue maximisation*. We consider how spectrum auctions may be an attractive source of revenue for governments as an alternative to further taxation. We also consider the effect of fixed and predictable annual fees against the alternative of a revenue share component within spectrum licences.

A key issue for spectrum auctions is their effect on *downstream competition* amongst spectrum licensees providing mobile telephony and data services. Even governments with an objective of raising revenue generally temper this objective with a need to promote downstream competition. Under this constraint, there is often surprisingly little difference between allocating spectrum to optimise its use (i.e. *efficient allocation*) and to maximise revenue. Indeed, many important features needed for a successful auction promote *both* efficiency *and* revenue, as we discuss in Section 3.

Nevertheless, the distinction between pursuing efficient use of spectrum and maximising revenue can become important in circumstances where competition for spectrum is weak. In these cases, it may be possible to 'tweak' auction rules to extract additional revenue from strong bidders who might otherwise win largely unchallenged.

In Section 4, we conclude by drawing out some of the key messages for best practice.

2 Objectives for spectrum auctions

Successful spectrum auctions need to be designed to fit the specific *circumstances* of a particular award in order to achieve clearly defined *objectives*.

Auction design is highly contingent, needing to be chosen to reflect the specifics of each particular spectrum award. In particular, auction formats and rules may vary depending on:

- the spectrum available for award and the range of potential competing uses for that spectrum;
- the likely extent of competition for spectrum (including the mixture of strong and weak bidders); and
- the impact of spectrum allocation on competition amongst network operators in downstream markets for mobile services.

However, what about the impact of the government's objectives for spectrum auctions? When we look globally, there is significant variation in the legal and policy frameworks for spectrum auctions. In this paper, we investigate how differences in objectives may affect the approach taken to selling spectrum.

We start by considering what objectives spectrum regulators might have. Very few governments take an approach of out-and-out revenue maximisation with no other considerations. If they did, they would allocate spectrum to create concentration in the hands of few operators – potentially even a monopoly operator – thereby creating market power in downstream markets; auctions can then be used to extract the profits created by market power to the benefit of the spectrum seller. Clearly, such an approach would be highly detrimental to consumers, with the ability to charge excessive prices for mobile services being the ultimate source of the higher willingness of operators to pay for spectrum in such circumstances.

Therefore, even governments that are interested in revenue raising through spectrum allocation do not treat revenue as the only objective. Where raising revenue is a consideration, this is usually modulated by other factors, such as the need to preserve effective competition in downstream markets.

2.1 What is efficiency?

Efficient allocation means spectrum being used in the way that generates greatest overall benefit from it. This simple definition raises some tricky issues:

- How should we define and measure the benefit to society from the services derived from spectrum?
- What range of alternative uses for spectrum we are prepared to consider when optimising its use?

There are both national and international institutions whose purpose is to determine the appropriate potential uses of a spectrum band. The ITU determines a frequency block "allocation" to primary and second uses under the Radio Regulations. National spectrum authorities must then respect these international treaties and may also pursue standardisation initiatives at the national or regional level that further restrict potential uses for a band. They must make policy decisions about what spectrum might be used for mobile services, what might be used for non-commercial services such as public safety or defence, and what might be used for services like satellite, broadcasting, fixed links and so on.

These high-level policy choices are not our concern here. Rather, we are interested in how a given spectrum band might be *distributed* amongst a number of potential users with a common identified use (or possibly a small range of alternative identified uses). Economists would call this problem – where a scarce resource such as a spectrum band must be distributed amongst different users - one of "allocation".[1] Efficient allocation requires a distribution of a spectrum band that achieves the greatest possible benefit within the constraints already set on how that band might be used.

In the EU, national regulators are largely obliged to have efficient allocation of spectrum as their primary concern, as discussed in Box 1. This is unsurprising as a policy objective given the critical importance of services derived from spectrum for the broader economy.[2] Mobile services are consumed not just by retail customers, but are also inputs into nearly every other sector of the economy. Significant productivity gains and innovations have resulted both from mobile voice services and, increasingly, mobile data services. Maximising the overall benefit to society from spectrum means allocating spectrum efficiently. However, not all jurisdictions take the approach of focussing exclusively on efficient allocation, as we shall see.

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[1] Therefore, there is inconsistent terminology. Spectrum managers commonly talk about "frequency allocation", meaning the identification of uses for a particular frequency range. However, economists use the term "allocation" more generally to mean choosing which of a number of incompatible demands on a scarce resource will be satisfied.

[2] For example, a study by Analysys Mason, DotEcon and Hogan and Hartson for the European Commission found that total value (private value plus public value) that could be generated from the digital dividend spectrum following analogue TV switchover could be €150bn to €700bn (in discounted terms over 15 years). See Analysys Mason, DotEcon and Hogan and Hartson, , *"Exploiting the digital dividend – a European Approach"*, Final Report for the European Commission, 14 August 2009.

BOX 1 – Objectives for spectrum allocation in the EU

European spectrum authorities must abide by the provisions of the Authorisation Directive (2002/20/EC). This Directive makes clear that payment for spectrum above its administration cost should be for the purposes of ensuring that spectrum is optimally used:

"… usage fees may be levied for the use of radio frequencies and numbers as an instrument to ensure the optimal use of such resources. … Where, in the case of competitive or comparative selection procedures, fees for rights of use for radio frequencies consist entirely or partly of a one-off amount, payment arrangements should ensure that such fees do not in practice lead to selection on the basis of criteria unrelated to the objective of ensuring optimal use of radio frequencies." [Recital 32]

Individually national spectrum authorities will have their objectives defined by specific national law, but this must be compatible with the general principles in the Authorisation Directive. For example, in the UK, the Communications Act (2003) defines Ofcom's general duties, which are primarily to further the interests of consumers and, where appropriate to promote competition [CA2003 §3(1)a]. Ofcom has a remit to secure *"the optimal use for wireless telegraphy of the electro-magnetic spectrum"* [CA 2003 §3(1)b]. Therefore, Ofcom's objective is very clearly one of efficient use of spectrum and promotion of competition, rather than maximising revenue.

Interestingly, one of the most famous examples of a high-revenue auction – the £22.4bn UK 3G auction – was run with an objective of efficiently allocating the available licences, with a reservation of spectrum for a new entrant to promote downstream competition. Therefore, the objective of efficient allocation may, obliquely, lead to high revenues anyway.

Provided downstream competition in mobile services derived from spectrum is effective, private and social valuations of awarding spectrum to specific licensees should align.[3] Under the proviso that downstream competition remains effective, the objective of achieving greatest social benefit from licences can be achieved by allocating them to whoever values them most. This might be through an auction or some other means, though auctions have the advantage of using competition between potential licensees to reveal who is prepared to pay most. Therefore, provided that measures are taken to ensure that downstream competition remains effective, auctions can provide a useful tool for a spectrum regulator wanting to achieve efficient allocation of spectrum.

[3] Private value is the profit of the licensee. Social value includes additionally benefits to users of services derived from spectrum (i.e. consumer surplus). Private and social values need not be equal, but should align in the sense that the licensee(s) with greatest private value should be those who can generate social value. This requires that licensees are addressing the same downstream market(s), these markets are competitive and that externalities are not significant.

The protection of downstream competition needs to be considered whenever there is potential that acquiring spectrum could restrict the ability of rivals to compete in downstream markets, as otherwise there could be anti-competitive motives to acquire spectrum.[4] Box 2 provides an example where flawed auction rules led to just this happening.

Box 2 – Bidding for downstream market power: the Turkish GSM auction

The Turkish GSM auction held in 2000 offered two GSM licences. The government wanted to maximise revenue, but in order to ensure that there were two operators in the downstream market, each bidder could acquire at most one of the licences. The government used sequential auction processes, in which one licence was sold after the other. Each auction was a sealed-bid where the winner paid the amount of its bid. The fatal flaw in the process was a requirement that the reserve price in the second auction be set at the price established in the first auction.

A smart bidder recognised the opportunity created by linking the reserve price for the second auction to the price established in the first auction. The value of a licence depended on whether there would be a two-player market – as the government hoped – or a one-player market. The bidder won in the first auction at a price above what any rival would reasonably pay for a licence in a two-player market, but still below the value for a licence in a one-player market. This in turn set the reserve price for the second auction, where no bidder was prepared to pay the reserve price set by the first auction for a licence in a two-player market. The government's objectives were not met, as only one licence was awarded.

Sequential auctions have been used previously (e.g. the Swiss WLL auction), but without the feature that reserve prices of future auctions being set by past auction prices. Although sequential auctions tend to perform poorly compared with simultaneous auctions (where multiple lots are sold in one unified process), there was no risk of the foreclosure problem that occurred in the Turkish auction. In the Swiss case, each auction had a fixed reserve price that had been previously announced at the beginning of the auction sequence.

The Turkish auction is a good example of where even small rule changes can have large effects on bidder's incentives that need to be taken into consideration. The main effect of linking the reserve price of the second auction to the price achieved in the first auction was to change bidding incentives in the first auction, not boost revenue from the second auction.

[4] Over time, this issue is probably becoming less important for individual bands due to the potential for alternative spectrum bands to be used to offer similar services. Therefore, cornering spectrum in one band may not pay if rivals are able to compete effectively using spectrum in other bands. However, certain bands may still be particularly important due to the sequencing of equipment availability or propagation characteristics (e.g. sub-1GHz spectrum).

2.2 Revenue maximisation

Spectrum sales are an important source of revenue for governments. Therefore, some governments have taken an explicit approach of *maximising revenue*, rather than pursuing efficiency.

An example is the Indian 3G and BWA (broadband wireless access) auctions, discussed in Box 3 below. The Indian government had an explicit objective of maximising revenue, subject to the requirement that there would be sufficient competition in downstream markets. As we will discuss later in Section 3, this led to some specific features of the auction rules, but the overall approach was not much different than would have been taken under a sole objective of efficient allocation.

BOX 3 – Revenue objective in the Indian auctions

Between April and June 2010, DotEcon implemented two auctions of radio spectrum on behalf of the Government of India, raising revenues of US$22.7 billion.

These auctions allocated multiple lots of spectrum in each of the 22 telecoms circles across India. Three or four 2x5MHz lots in the 2100MHz (3G) band and two 20MHz lots in the 2300MHz (BWA) band were made available in each circle.

Both auctions used a modified clock auction format, designed specifically to fit the circumstances prevailing in the telecoms market in India and to meet the objectives of the Government for these particular awards.

In contrast to spectrum awards in Europe, which have the efficient allocation of spectrum as their objective (see Box 1), one of the main objectives in the Indian auctions was *revenue maximisation* and this was explicitly part of the auction designer's brief. This objective was subject to the constraint that effective competition in downstream markets must be promoted. For this reason, bidders could bid for at most one lot in each circle.

Revenue maximisation is a different objective to efficient allocation of spectrum. Nevertheless, these distinct objectives often lead to similar approaches in practice *provided that these objectives operate within the constraint of maintaining effective downstream competition*.

Achieving efficient allocation leads to revenue being raised whenever spectrum is scarce and demand outstrips supply. Conversely, achieving maximum revenue will require spectrum most likely being allocated to whoever values it most (provided that excessive concentration of spectrum is prevented and downstream competition remains effective). We return to the question of identifying the ways in which these objectives differ in Section 3, where we will find that quite sophisticated analysis is needed to identify the differences.

2.3 Spectrum auctions and public finance

Is it reasonable for governments to use spectrum as a source of revenue to support public finances?

Spectrum auctions can raise significant amounts of money that can have an effect on public finances. For example, the UK 3G auction raised £22.4bn (though this was an exceptional auction). To put this amount in context, to raise that amount through income tax in one year, the UK government would have needed to raise income tax rates by about 10p in the pound. The recent Indian 3G and BWA auctions made a material contribution to government revenues (US$22.7bn).

For a government with a certain revenue requirement, the main alternative to raising money from spectrum sales is to raise money from general taxation. However, raising tax necessarily leads to *distortions* within an economy, as decisions to work, save and invest are affected at the margin. For example, income taxes may affect how much time someone spends working and when they retire. Therefore, the key question for public finance is how to raise the money that a government needs from a mix of possible sources in order to keep these distortions to a minimum.

For this reason, spectrum auctions are an attractive source of revenue for government. Provided they are properly implemented, spectrum auctions should not create significant economic distortions. However, avoiding distortions requires that:

- the rights and obligations associated with spectrum licences are clear to bidders at the time of the auction and the spectrum regulator is able to commit credibly that terms and conditions will not be changed subsequent to the award;
- any on-going charges during the life of the licence are known (to a reasonable degree) at the time of the spectrum award;
- downstream competition in services will be effective; and
- the auction achieves efficient allocation of spectrum.

Successful auctions require clarity about what is being sold, so that bidders can value the items and bid accordingly. Where there is uncertainty about the rights and obligations associated with spectrum licences, it is difficult to estimate value. Under such circumstances, the issue of who wins may depend not on the spectrum valuations of bidders but on bidders making different assumptions about how the spectrum regulator might behave in the future. To achieve efficient allocation, therefore, there needs to be clarity, certainty and predictability surrounding the conditions of resulting licences.

These principles apply particularly to any charges levied over the course of a licence. It is not uncommon to have annual charges for spectrum licences (not least so that there is an incentive to return any unused spectrum). Provided that these charges are predictable over the life of the licence, they can be factored into bidders' valuations and will result in a corresponding reduction in auction prices. Therefore, predictable annual charges act primarily to defer payments for spectrum, but should not otherwise affect auction outcomes.

If operators' incentives to use spectrum licences are to remain undistorted, it is important that any future on-going spectrum fees are fixed outside the influence of the licensee or the control of the licensing authority.[5] This contrasts with approaches where an on-going fee is determined by turnover (or other operational parameters under the control of the operator). The Hong Kong 3G auction (Box 4) provides an example. Whilst turnover related fees over the course of a licence might seem attractive for a government, as it captures some of the upside benefit of the spectrum, any significant revenue share can lead to distortions of commercial decisions just like a conventional tax.

Box 4- The Hong Kong 3G auction

In 2001, OFTA, the Hong Kong telecommunications authority held an auction to license 3G spectrum in the country. Hong Kong had a highly competitive market with six incumbent mobile operators and OFTA ultimately decided to divide the available spectrum into four identical licences, each consisting of an unpaired 5MHz block and a 2x14.8MHz paired block of spectrum, all in the 2.1GHz spectrum band. By selling identical packages of spectrum, OFTA hoped to allow four operators each to offer full 3G services, balancing competition and service levels.

The auction took place over three phases: in the first, operators bid percentages of turnover they would offer as an annual fee, with each of the four winners paying the lowest winning fee. The second phase would remove any connections between bidders, and the final phase provided a pay-your-bid, sealed bid format to allow winning operators to select their preferred block of spectrum.

After the initial stage, four bidders were successful with each offering paying 5% of their revenue as an annual royalty in years 6 to 15 of the licence, with a minimum fee that rose year-on-year. Over the first 5 years, each operator would pay the same HK$ 50 million annual royalty, to balance the effects of different business plans. The final price paid was comparatively low by international standards around that time.

For example, suppose that an operator was considering which one of two projects to pursue: the first to boost revenue and the other to cut cost. Suppose that both had the same implementation costs and the same impact on operating profits. There would be a bias against the revenue-boosting project because it would lead to additional revenue-related spectrum charges, unlike the cost-cutting project.

Therefore, revenue-related spectrum fees can depress incentives to roll out new services and to win customers from other operators. They may also affect pricing for customers, as the revenue share is, in effect, a *marginal cost* on every additional service

[5] Here we used the term "fixed" to include situations where there are changes in spectrum fees over time, but these changes are outside the control of both the licensee and the licensing body. For example, if fees grow at a fixed rate over time, or if fees are indexed by inflation, then future fees can be anticipated at the time of licensing and do not depend on any actions that the licensee might take.

sold or customer served. In contrast, a payment for a spectrum licence is a *fixed cost* that should have little effect on pricing decisions or incentives to compete.[6]

Therefore, the best approach even for governments interested in raising revenue is to use auctions to extract the value of spectrum through up-front charges, rather than using revenue-sharing arrangements that will distort operator's incentives. Where revenue-share components are included in the terms of spectrum licences, the advantage of an auction in being a relatively undistorting source of government revenue is in part lost. Further, revenue-sharing arrangements may lower the value of spectrum at auction by more than a government can expect to earn back in the future through additional spectrum charges.

[6] Clearly, if fixed costs are sufficiently large, then they may affect the ability of an operator to raise capital or, at the extreme, make an operator unviable and so affect market structure.

3 Efficiency vs. revenue maximisation

In this section, we explore in more detail the relationship between the ability of auctions to raise revenue and efficiency of auction outcomes. The key point is that if a government does not concern itself about downstream competition in mobile service markets, then efficient allocation of spectrum and maximising revenue are diametrically opposing objectives. However, if that government operates under the constraint that it wants effective downstream competition, then the objectives of efficient allocation and maximising revenue are closely, but not entirely, aligned.

Put simply, any method of allocating spectrum efficiently must create at least some revenue whenever demand for spectrum outstrips supply. Conversely, maximising revenue entails allocating spectrum (with sufficient probability) to those who value it most; subject to downstream competition being effective, these bidders should be those who can create greatest overall benefit. This is why the two objectives broadly align. However, this alignment is not perfect, as there are situations in which auction designs can be 'tweaked' to get a little more revenue at the expense of a small loss in efficiency.

3.1 Opportunity cost as a minimum payment

Regardless of whether we use an auction or some other method to allocate spectrum, what should the licensee then pay? The need to prevent objections from losers sets a *floor* on this payment. Box 5 provides a very simple example of how this minimum payment is calculated with a single spectrum licence. The licensee needs to pay at least the amount that the highest value alternative user of the spectrum would be prepared to pay. This is the so-called *opportunity cost* of awarding the spectrum – the lowest price that is compatible with losers not wanting spectrum from winners.[7]

There is a very close relationship between *efficient allocation* of spectrum and *opportunity cost*. In particular, efficient allocation is achieved if (and only if) the licensee would be prepared to pay the opportunity cost. For example, suppose that we had a single licence that was awarded to one party, but someone else was prepared to pay more for it; this would not be an efficient allocation as the licence could be reallocated to someone else who valued it more highly.

Therefore, any efficient allocation *requires* licensees to pay at least the opportunity cost they impose otherwise there will be unhappy losers. An efficient allocation requires a certain minimum amount of revenue to be raised (regardless of whether an auction or some other allocation method is used).

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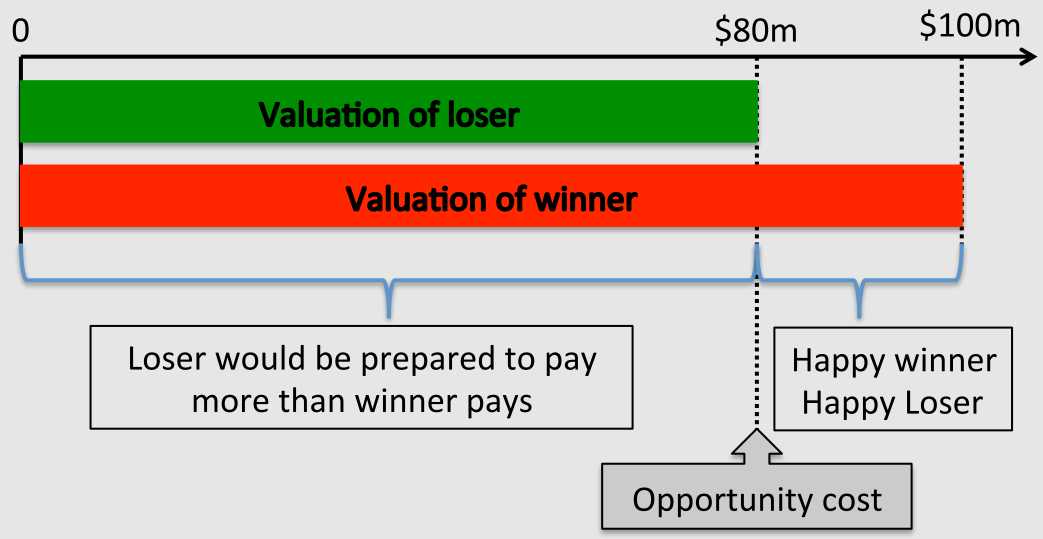
[7] Many of the latest generation of combinatorial clock auction – as used in the UK, Netherlands, Denmark and now proposed for use in auctions in Australia, Ireland, and Switzerland – use a very similar approach to determine prices to be paid by winning bidders, so-called *core pricing*. Winning prices are such that no bidder or group of bidders could make a greater counter-offer to the seller at prices not exceeding their bids. Therefore, winning prices are determined by a "no unhappy losers" requirement. These auctions use a generalised concept of opportunity cost that sets a floor not just on what individual winning bidders pay, but also groups of winning bidders. See http://www.dotecon.com/publications/dp0701.pdf for a discussion of core pricing methods.

BOX 5 – Opportunity cost in a very simple auction

Suppose that a single licence is being auctioned through a simple *open auction*. Bidders can increase their bids until there are no further bids. The licence is allocated to the highest bidder who pays its bid.

The strongest bidder values the licence at $100m, whereas the next strongest only values it at $80m. Clearly, the auction cannot close until bids have reached the level of $80m. We would expect the strongest bidder to win, but to pay only $80m even though it values the licence at $100m. The *opportunity cost* of awarding the licence to the strongest bidder is $80m, as the alternative allocation of the licence is to the next strongest bidder and $80m is the amount that this next strongest bidder would be prepared to pay.

Notice here that there is a range of prices ($80m to $100m) that the winner is prepared to pay (in that they do not exceed its valuation) and which keeps the loser happy. The opportunity cost is the lowest price compatible with the loser not wanting to make a higher counter-offer for the licence exceeding the price paid by the winner.



Auctions reveal an efficient allocation (and the associated opportunity costs) through a competitive process. With a properly designed process there should be no unhappy losers. However, avoiding unhappy losers is also desirable for administrative award of spectrum if complaints of subsidy are to be avoided. If spectrum is licensed at below opportunity cost, then there will be some other party who can complain that it would have been prepared to pay more and that the licensee is paying less than the true market value of the spectrum.

Therefore – as a very general proposition – efficient allocation of spectrum requires a certain *minimum* amount of revenue to be raised. Even a government with an objective of efficient allocation will typically need to raise some revenue.

3.2 Is there untapped revenue?

One issue for the design of a mechanism for spectrum allocation is whether it might it be possible for a government to raise *more* revenue than the minimum needed to support an efficient allocation. In particular, the gap between what a licensee is prepared to pay for a licence (i.e. its valuation) and the opportunity cost (i.e. the valuation of the next strongest bidder) may be significant. Where this is this case, a licensee will enjoy some surplus where the price paid for its licence is based on opportunity cost. This is the case in the example shown in Box 5, where a revenue maximising seller would ideally like to capture some of the $20m surplus that the licence winner would enjoy in an open auction.

Could the seller capture some of this surplus as greater revenue? While the question appears to be a simple one, the answer is not straightforward.

In short, it is not easy for the seller to extract this surplus from the winner. This is because the seller is unlikely to know the valuation of the highest bidder with any precision. Indeed, the very fact that an auction is being run suggests that the seller does not know who is likely to be the strongest bidder nor how much they might be prepared to pay. Therefore, simple approaches to try to capture the winner's surplus, such as setting a reserve price somewhere between the winner's valuation and the strongest loser's valuation, are unlikely to be successful. There is a chance such a strategy might get the winner to pay more, but this is counterbalanced by a high risk that the lot would go unsold, generating no revenue at all.

Is there is a better way to extract the winner's surplus, for example through a particular auction format or clever auction rules? To better understand the issue, economic theory has provided a *negative* answer to this question under certain conditions. The famous *Revenue Equivalence Theorem* (RET) tells us that - in certain circumstances - it does not make any difference what auction rules are used provided that they lead to efficient outcomes; all rules generate the same expected revenue.[8] Box 6 below explores this result.

The implications of RET are often misunderstood, as everything rests on its assumptions. It certainly does *not* say that auction rules do not affect revenue; what it does is to clarify *when* auction rules affect revenue, as these must be circumstances in which the RET's assumptions do *not* hold.

In particular, the RET only considers situations in which the auction mechanism always leads to efficient outcomes. Although most auction mechanisms have the property that the highest *bid* wins, this does not automatically mean that the bidder with the highest *valuation* wins, as this depends on how bidders choose to bid. Depending on the incentives created by the auction mechanism, bidders may choose not to bid their valuations and so the highest value bidder may not win.

[8] The RET tells us about expected revenue – what the seller would expect to earn on average – if it could re-run the auction with different sets of bidder valuations drawn from underlying probability distributions. However, different auction rules may still vary greatly with regard to the variability of the revenues that they create; the RET says nothing about this.

BOX 6 – When auction rules don't matter: the Revenue Equivalence Theorem

The Revenue Equivalence Theorem (RET) is a famous mathematical result in auction theory that was first demonstrated by Vickrey in 1961.[9] It says that a seller's expected revenue is independent of the auction rules provided:

- bidders have fixed valuations that do not change in the course of the auction;
- bidders do not care about risk (they are risk-neutral, which may be a reasonable assumption if the bidder is a company with diversified shareholders);
- the auction rules are such that the bidder with the highest *valuation* always wins (i.e. the auction outcome is always *efficient*); and
- a bidder in the weakest possible situation (i.e. with lowest possible valuation) cannot expect to receive any surplus from the auction.

At first sight this is very surprising, as the auction rules might be very different, yet generate the same expected revenue. For example, consider:

- an *open ascending* auction, where the price increases until there is only one bidder remaining; and
- a *first-price sealed bid auction*, where each bidder makes just one offer without knowing what offers others have made and pays the amount of its offer if it is highest and wins.

These auctions are strategically quite different. In the open auction, bidders can adopt the simple strategy of remaining in the bidding until the price exceeds their valuations, in which case they make no more bids. In the sealed bid, each bidder needs to form some assessment of the competition and bid some amount not exceeding its valuation. Bidding a greater amount will give a greater chance of winning, but the bidder will pay more if it does win; therefore, a compromise will need to be struck.

Despite these auctions being so different, they create the same revenue on average for the seller under these conditions. In a sealed bid, the winning bidder will bid strictly less than its valuations. In the open auction, the winning bidder pays the valuation of the second strongest bidder, not its own. On average, these both lead to the same revenue.

3.3 Auctions with asymmetric bidders

What about an auction mechanism that does not always produce efficient outcomes? This would not be subject to the RET. Could it generate more revenue?

In fact the answer is yes – in some circumstances, auction formats that do not always produce efficient outcomes can create greater revenue. However, we must also remember that there is a limit on the additional revenue that can be achieved. A

[9] See Vickrey, W., (1961) "Counterspeculation, Auctions, and Competitive Sealed Tenders," Journal of Finance, 16, 8-37.

grossly inefficient auction mechanism will be bad not just for efficiency, but also for revenue, as the strongest bidder will seldom win.

Box 7 looks at a simple case in which a seller might want to use an auction design that does not always lead to efficient outcomes because it generates more revenue on average. When one bidder is stronger than its rivals, a sealed bid auction might create more revenue than an open auction by challenging stronger bidders to a greater extent than an open auction.

BOX 7 – Asymmetric auctions

Consider a very simple situation in which there are two bidders (*Red* and *Green*) competing for a single lot. We suppose that each bidder has a fixed valuation that is unknown to the other bidder and does not change in the course of the auction (so-called *private valuations*).

Consider first an *open auction*, in which the price of the lot increases until there is just one bidder left. This will happen when the price reaches the valuation of the weaker bidder. The bidder with the highest valuation always wins the lot. Therefore, the outcome is efficient.

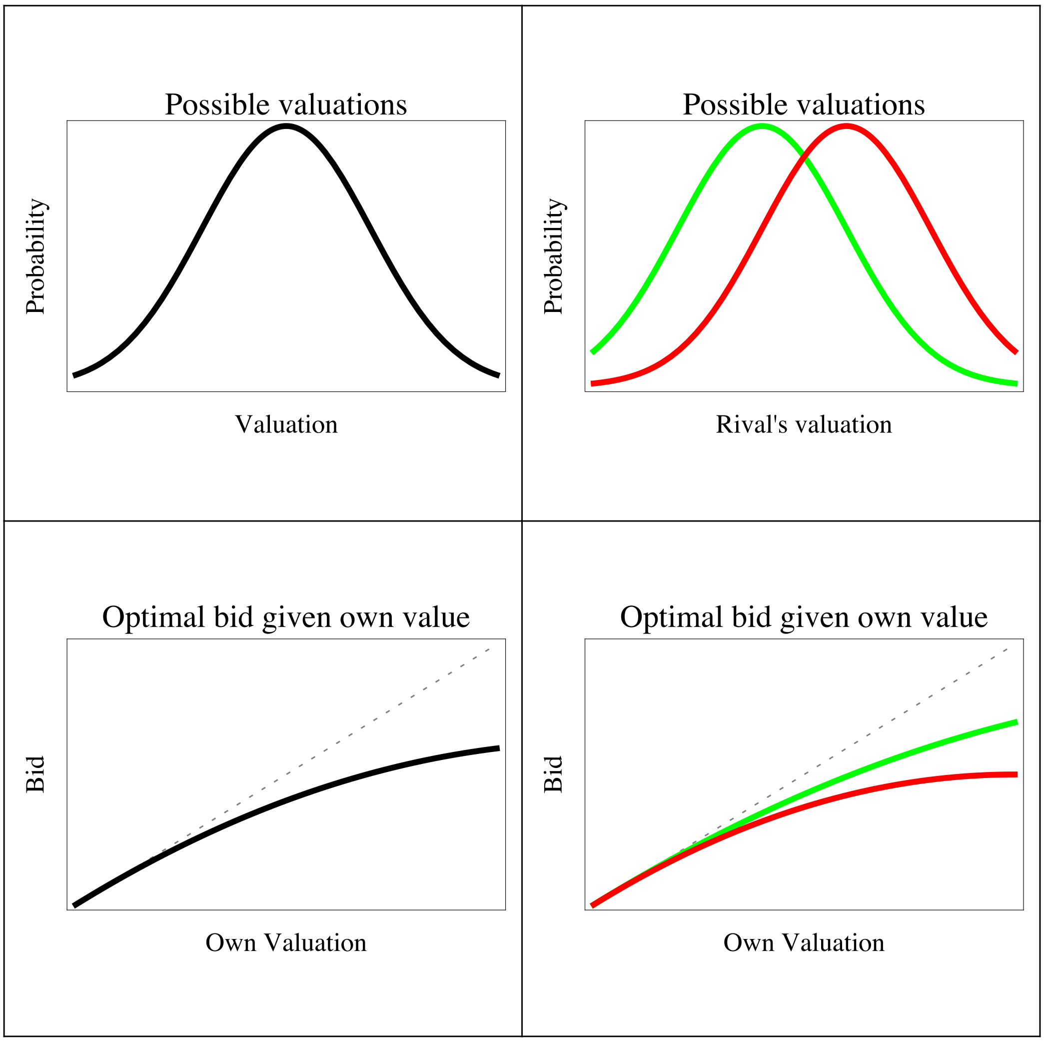
Now consider a simple *sealed bid auction*. Each bidder simultaneously announces a single bid. The highest bidder will win and pay the amount of its winning bid. How does each bidder determine the best bid to make? It needs to trade off the probability of winning – which increases the more it bids – with the surplus it obtains if it does win. This is illustrated in the left hand pair of diagrams below.

Each bidder does not know the valuation of its rival, but believes that its valuation is drawn from some probability distribution. Let us start by assuming that there is *symmetry*, with each bidder thinking that it is just as likely to have a higher valuation than its rival as it is to have a lower valuation. Therefore, Red's belief about Green's valuation is the same as Green's belief about Red's valuation. A third party not knowing the precise valuation of each bidder would say that Red and Green were equally strong.

Now a bidder with a low valuation (i.e. to the left in the probability distribution) will judge that it is very likely that its rival will have a higher valuation; therefore, it is under strong competitive pressure and will bid a large part of its valuation. Indeed, at very low valuations, the bidder will need to bid almost its entire valuation and will gain only tiny surplus in the unlikely event that it does win. However, a bidder with a high valuation (i.e. to the right in the probability distribution) will judge that it is likely to beat its rival; therefore, it does not need to bid such a large part of its valuation and will gain significant surplus if it does win.

The bottom-left diagram shows the optimal bid depending on the bidder's realised valuation. Higher valuations lead to higher bids, but with an increasing gap between valuation and bid. With symmetric bidders each having the same relationship between valuation and optimal bid, the bidder with the higher valuation will always win. Therefore, with symmetric bidders, the sealed bid auction is always efficient. The RET (see Box 6) then tells us that, on average, the sealed bid auction will generate the same revenue as the open auction.

Now suppose that Red is the stronger bidder and Green the weaker bidder. These *asymmetric* beliefs about valuations are shown in the top-right diagram, with Red believed to have higher valuations. Of course, it might be that Green turns out to have the higher valuation in practice, but this is less likely than Red having the higher valuation.



Because Red knows that it is in a stronger position, for any given valuation it will bid less than Green would if it had the same valuation. This is shown as two different relationships between a bidder's valuation and its optimal bid – the lower one for Red and the higher one for Green.

When bidders are asymmetric, it does not follow that the auction outcome is necessarily efficient. In particular, it is possible that the Red bidder has a higher valuation than Green, but nevertheless bids less than Green and so loses. This happens precisely because Red is trying to capitalise on its advantage relative to Green by bidding less and getting more surplus if it wins.

Therefore, an asymmetric sealed bid auction is not always efficient, as the highest *value* bidder does not necessarily win even though the highest bid wins. Because the conditions of the RET do *not* hold, the sealed bid does not necessarily generate the same expected revenue as the open auction when bidders are asymmetric.

Does the sealed bid generate more or less revenue than an open auction when bidders are asymmetric? This depends on the exact details of how the bidders differ.[10] However, in many reasonable situations with the features described here, expected revenue is greater from a sealed bid than an open auction once bidders are asymmetric. The issue with the open auction under such circumstances is that the strong bidder will only ever pay the valuation of the weak bidder, which on average might be a lot less than its own valuation. However, in a sealed bid situation, the strong bidder has much to gain from winning – as it valuation tends to be high – and the weak bidder has to bid aggressively to make up for its disadvantage. This limits the ability of the strong bidder to enjoy its position of strength by bidding much less than its valuation.

Therefore, when bidders are asymmetric, a sealed bid can in some cases generate more revenue than an open auction. However, this is intimately linked to the fact that the strong bidder might not always win, even if it has the higher valuation. Therefore, greater revenue comes at the cost of reduced efficiency.

3.4 The example of the EU 3G auctions

The sequence of 3G auctions held in Europe provide an interesting natural experiment of the impact of bidder asymmetries, as the same spectrum was available in each country, cost and demand conditions were similar and the various auctions at similar times (during 2000 and 2001). However, outcomes were quite different.

The first auction in the sequence was the UK 3G auction, run in March and April 2000 (see Table 1 below). This used an open ascending auction format, with each potential licensee bidding for just one lot. There were five licences available, with one reserved for entrants. This attracted 14 bidders and was highly competitive, raising £22.4bn in total for the UK government. Although efficient allocation, rather than raising revenue, was the objective, the auction was spectacularly successful for the UK government in bringing in revenue. This was due in part to the auction's timing – just at the peak of the telecoms, media and technology (TMT) equity bubble that drove up entrants' valuations – but it was also due to the high level of competition.

However, subsequent auctions demonstrated a much lower degree of competition. In particular, the Dutch 3G auction occurred soon after in July 2000, before the bursting of the TMT bubble. However, it was much less competitive. The problem was that there were only as many strong bidders as licences available (four), with one weak entrant providing all the competition (Versatel). With an open ascending format[11], prices were determined by the price at which this weak bidder dropped out. The

[10] See Eric Maskin and John Riley (2000) "Asymmetric Auctions", The Review of Economic Studies, Vol. 67, No. 3 (July), pp. 413-438.

[11] In fact prices went *down* for some of the early rounds in the Dutch auction due to the flawed auction rules adopted.

Dutch government earned less than one-third of the revenue that had been predicted after the UK auction.[12]

Table 1: Outcomes of selected European 3G auctions

Country	Date of auction	Bidders / licences available	Reserve price per capita (euros)	Price per capita (euros)	Dow Jones Telecom Stock Index (approx.)
UK	Apr 2000	14/5	2.9	128.5	1250
Netherlands	Jul 2000	5/4	2.7	33.7	1000
Italy	Oct 2000	6/5	35.8	42.2	800
Denmark	Sep 2001	5/4	12.6	23.9	50

Notes: (i) One of the five licences in the UK was reserved.
(ii) The telecoms stock index is an approximate value around the time of the auction.

A similar issue arose in the Italian 3G auction run in October 2000, but there were six bidders for five licences. Price did not increase much above reserve prices, as only a few rounds were run. However, unlike the Dutch auction, the reserve price had been set fairly high, reducing the impact of weak competition on revenues.

How could competitive conditions change so rapidly in a matter of months? The UK auction demonstrated that existing 2G operators were likely to have the strongest business cases, with the four incumbents winning the unreserved licences. However, entrants were still attracted by the chance of winning the reserved fifth licence. Competition for this reserved licence in effect set the price for the unreserved licences. There was further competition amongst the four existing 2G operators for one large licence.

In situations where there were as many licences as 2G incumbents – as in the Dutch and Italian auctions – then it was unlikely that entrants would be successful. As a result, participation was much more limited, in each case attracting just one weak outsider in each case. Given the asymmetry between bidders, an open ascending auction resulted in low revenues.

In contrast, the Danish 3G auction in September 2001 used a sealed bid rather than the more common open ascending auction that had been used in the previous 3G auctions. Just like the Dutch and Italian auctions, there were as many licences as there were existing operators. However, by this time the TMT equity bubble had most certainly exploded (see Table 1). Unlike the Dutch and Italian auctions, the Danish

[12] See Paul Klemperer (2002) "How (not) to run auctions: the European 3G telecom auctions", European Economic Review, 46, 829-845.

attracted a reasonably serious entrant and generated revenues significantly above reserve prices.

3.5 Why are sealed bids not more widely used?

Most spectrum auctions are *open, multiple round auctions* of some form – the Simultaneous Multiple Round Ascending (SMRA) auction pioneered by the US FCC during the 1980s – or the Combinatorial Clock Auction (CCA) pioneered by Ofcom in the UK. Why is this?

Despite the apparent "success" of the Danish 3G auction in the face of weak competition, sealed bid auctions are not commonly used. The main concern is that they do not allow bidders to gain information from the bids of others in order to refine their valuations and reduce so-called *common value uncertainty.*

In practice, we cannot treat bidders as having fixed and independent valuations. All operators are affected by common uncertainties about future demand for their services, cost and technology conditions. A forecast must make use of all these various factors in order to value spectrum. Where new spectrum is needed to offer new services (as in the initial licensing of spectrum for 3G and, arguably, with spectrum intended for 4G) these risks may be substantial.

In these situation, rivals' valuations contain useful information about their assessment of factors affecting profitability that might be relevant to a bidder's own valuation. Therefore, a bidder might update its own valuation downwards if it sees other bidders dropping out of an open auction sooner than expected or upwards if it sees rivals staying in at higher prices than expected. Even where auctions have limited transparency (as is common with the newer CCAs) bidders will still usually get information about aggregate demand, which again is useful for updating their own valuations. As with any market, an auction provides a means of combining information held by different parties into a common view about value.

Open auctions reduce common value uncertainty for bidders. Reduced uncertainty has a number of advantages, both for bidders and for the seller. Common value uncertainty exposes bidders to *winner's curse*; this is the risk of winning due to an over-optimistic valuation. To avoid winner's curse, bidders need to bid more conservatively; this tends to lower revenue for the seller.

Common value uncertainty is also bad for efficiency. A bidder might win not because it has the highest valuation *given the information available at the end of the auction*, but rather simply because it made an over-estimate of the value of spectrum prior to the auction. Once there is common value uncertainty, we cannot suppose that bidder's estimates of the value of spectrum necessarily incorporate all available information prior to the auction, as other bidders might hold some relevant information. Different auction formats provide different amounts of information to allow valuations to be refined. Sealed bids do not provide any such information. Open ascending auctions of various types can provide information about other bidders' valuations depending on the transparency rules adopted. Some open auctions might allow all bids received so far to be seen, whereas other auctions might only allow for anonymous summaries (i.e.

total demand for lots in the last round but no information on the individual bids of other bidders)[13].

Therefore, for an auction designer with an interest in revenue there is a trade-off. Broadly speaking, sealed bid mechanisms can be useful for situations in which competition for spectrum would be very weak, even where there is winner's curse.[14] However, open auction formats tend to be more useful in reducing the impact of common value uncertainty providing there is reasonable competition for spectrum.

Does the use of a sealed bid – possibly embedded in more complex rules – mean that the auction designer is only interested in revenue? We need to be careful here to avoid making excessively bold inferences.

Even a government with no interest in revenue and with efficient use of spectrum as its sole objective might in certain cases want to adopt this (or similar) approaches. In practice, there may be concerns about the relative strengths of existing operators and new entrants in bidding for spectrum or even, in some cases, the relative strength of operators earlier to market relative to later starters. Of course, provided downstream competition in mobile services is effective and not at risk of being weakened by any bidder cornering the market for spectrum, none of this should matter. However, in some markets, increasing downstream competition might be a concern for a spectrum regulator and a variety of measures might be used to limit the ability of relatively strong market players becoming relatively strong bidders for a new spectrum band. This might be a spectrum cap, or measures to tip the playing field slightly in favour of weaker bidders, including possibly sealed bids or measures to limit transparency in open auctions. Therefore, a spectrum auction might be use as an active policy instrument to affect downstream competition.

In practice, spectrum auction designs have tended to steer away from sealed bid approaches (at least for key spectrum bands). Bidders often oppose such auctions for two main reasons.[15]

First, there is the practical issue that, with just one chance to make a bid, business planning and valuation takes on great importance. If a bidder loses a sealed bid due to an error in its assessment of spectrum value, there is no second chance to revise this. Therefore, bidders often argue that sealed bids create much greater business risks for them than open auctions. Even if common value uncertainty is usually of minor importance for bidding strategies (as bidders would not typically update their

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[13] This approach is now common for CCAs, as it allows bidders to gain relevant information about overall market demand, but not to condition their bidding strategy on the specific bids of rivals. This reduces the risks of tacit collusion amongst bidders and possible predatory bidding behavior.

[14] There are further issues to be considered in situations where there are both asymmetries between bidders (i.e. some are known to be weak and others strong) and strong common value uncertainty. Winner's curse has a stronger effect on weaker bidders than stronger bidders. Therefore, common value uncertainty can reinforce bidder asymmetries. See for example Paul Klemperer (1998) "Auctions with Almost Common Values: The 'Wallet Game' and its Applications", European Economic Review, 42(3-5), May, 757-69.

[15] In addition, simple sealed bid auctions cannot deal adequately with lots that might be substitutes or complements. However, more complex one-shot auctions – such as combinatorial sealed bids – can address these problems. Such an approach was used in Ireland for 26GHz spectrum in 2008.

valuations significantly in the course of an open auction) there is still the matter of bidders making substantial valuation errors to be considered, where the ability to learn may be important.[16] It would typically be in the interest of a government selling spectrum to ensure that auction outcomes are not excessively sensitive to valuation errors, as this risks inefficient use of spectrum and, in the worst case, creating an unviable winner.

Second, as we have seen above, sealed bids tend to give weaker bidders a small chance of winning that they might not have had in a open auction and to challenge strong bidders who cannot risk losing a large surplus. Therefore, unsurprisingly, stronger bidders – who often tend to be existing operators – tend to favour rules that favour them, which are typically open processes and increased transparency. Weaker bidders favour rules that give them a chance of sneaking a win, which are typically sealed bids and reduced transparency. Weaker bidders lose the opportunity to correct their own valuation errors, but hope that this advantages them because a rival bidder might make a valuation error to their advantage. Put simply, weaker bidders would prefer a greater role for chance, whereas stronger bidders would favour a smaller role.

3.6 Designing auctions for efficiency *and* revenue

For an auction designer, moving to a straight sealed bid process may be a disproportionate response to concerns about bidder asymmetries if the risk of inefficient outcomes due to common value uncertainty is significant. Nevertheless, this approach may sometimes be appropriate if there is no other means to ensure effective competition for spectrum. Before turning to such options, we need to ensure that there are not other more proportionate tools to address the problem, in particular:

- encouraging participation by bidders; and
- using flexible auctions that maximise competition amongst bidders.

First, *auctions are more effective with more bidders*. Therefore, it is essential to ensure that where auctions are run it is attractive to participate. This is a blindingly simple point, but its practical importance cannot be emphasised too greatly.

Potential bidders need to be clear what they are competing for and have confidence in the auction process. The rights and obligations associated with spectrum licences need to be clear and credible. There needs to be commitment from a spectrum regulator not to change the terms of spectrum licences after they have been issued without good reason and then only within a defined framework previously laid out prior to any auction. A perceived risk of 'hold-up' – where a licensee finds that licences cannot be used as expected when it bought them - can greatly depress the expected value of spectrum. Therefore, a clear and credible regime for managing spectrum is a

[16] To be clear, for there to be any ability of an open auction to allow correction of valuation errors, there must some relationship between bidders' valuations and hence an aspect of common value uncertainty. If each bidder had entirely idiosyncratic valuations, then there would be no capacity to "check" valuations from observing the bids of others. However, at the same time, it is possible that little updating of valuations under typical conditions where no bidders have made significant valuations errors.

prerequisite for good participation. This is to the benefit of both governments either seeking revenue or efficient outcomes and for bidders wanting to reduce risk.

Second, even in cases where there are a limited field of bidders – for example where a band is primarily of interest to existing operators only – this does not mean that effective competition is impossible. There may still be significant potential for competition between a limited field of bidders over the *amount* of spectrum won.

Until fairly recently, spectrum auctions have often tended to involve bidding for lots with a fixed allocation of spectrum. In effect, one lot is one licence for one operator. If there are existing operators who need spectrum in a new band and the amount of available spectrum is limited, this can easily lead to a situation in which the number of lots available is equal to the number of existing operators who form the "strong" bidders. This was the problem is some of the European 3G auctions, as we have discussed above. However, what if competition over the amount of spectrum won by strong bidders is possible?

With good auction design, it may be possible to create effective competition even if there is a limited field of participants provided that there is flexibility in the amount of spectrum that bidders may bid for. Competition may then come from bidders competing not just over price, but also for larger versus smaller amounts of spectrum. However, this does require auction formats that provide good incentives to compete for additional spectrum, as we discuss in Box 8 as well as flexible spectrum packaging.

BOX 8 – Competition over the amount of spectrum won

Where bidders can compete over the amount of spectrum that they win, there is a danger that bidders might choose simply to make do with a smaller amount of spectrum in order to get a lower price per megahertz on the spectrum it does win. This behaviour is sometimes called *strategic demand reduction*. This has been observed in the SMRA (simultaneous multiple round ascending) auctions commonly used in the US and Canada. Clearly, such behaviour is bad for both efficiency – as it might have been better for a bidder to win more spectrum – and for revenue – as competition in the auction might be dramatically limited.

The extent of this problem depends greatly on the auction rules used. It can be largely eliminated by using a combinatorial clock auction (CCA). In a CCA, there is typically a pricing rule that determines what each winning bidder must pay by reference to that bidder's opportunity cost, rather than what the bidder actually bid. As a result of such a pricing rule, if a bidder competes for a larger amount of spectrum unsuccessfully, this does not drive up the cost of then acquiring a smaller amount of spectrum as a backup strategy.

The Danish 2.6GHz auction in 2010 provides a good example of how the CCA may be more effective than the SMRA in protecting awards from the effects of demand reduction. This award took place one year after a similar award in neighbouring Sweden and had a similar cast of bidders. Specifically, in both auctions, the only bidders for FDD spectrum were the four incumbents, with aggregate demand of 16 lots (4 lots of 2x5MHz each) against 14 lots supply. Sweden used an SMRA format, which ended with healthy prices after H3G eventually dropped back from 4 to 2 lots.

In Denmark, H3G was again likely to be the marginal bidder. Had Denmark used an SMRA format, a good strategy for H3G to adopt would likely have been to drop immediately to 2 lots, allowing all bidders to win spectrum at the reserve price; this would have been a sensible approach in light of the Swedish outcome which suggested that H3G would be unlikely to win more than 2 lots.

Instead of using an SMRA, Denmark adopted a standard CCA, which allowed for package bidding. As a result, H3G was able to bid up to its maximum willingness to pay for 4 lots, before dropping back to 2 lots without any price penalty for the lots that it eventually won. This is because the price that H3G paid was determined by the opportunity cost associated with the 2 lots it won, which was not affected by its unsuccessful bids for 4 lots. The revenue per capita achieved in Demark exceeded that in Sweden even though the same amount of both paired and unpaired spectrum was allocated in both awards.

Measures both to promote participation by bidders and to maximise the extent of competition between bidders are desirable *regardless* of whether a government is pursuing a pure efficiency goal or a revenue goal. Therefore, there are many important aspects of auction design that do not require a choice between revenue and efficiency; we can have both.

3.7 Tweaking auction rules for revenue

Let us assume now that a government has done all it could to promote participation by creating attractive licences within a credible regulatory regime and avoided unnecessary uncertainty about the rights and obligations of licences. Competition amongst bidders has been maximised, possibly using flexible spectrum package allowing quantity to be an additional dimension of competition alongside price. Is there any more that can be done to increase revenue without weakening downstream competition in mobile services?

We have already taken all measures that might increase *both* revenue *and* efficiency. Therefore, the only remaining question is whether we might get more revenue by conceding some efficiency, as we found was sometimes possible with a sealed bid auction where there are weak and strong bidders (see Section 3.3 above). However, there are constraints on the expected revenue that can be obtained that depend on exactly how the auction is configured and the nature of competition amongst bidders. It is not possible to increase expected revenue beyond what can be achieved from efficient allocation unless there are asymmetries between bidders.[17] In such a case, it may be possible to use a threat of not winning to extract additional revenue from strong bidders, but with a consequent loss of efficiency. Clearly we cannot travel too far down this path without *reducing* revenue if the probability of the strongest bidder winning falls too much. The 'tweak' should push the strong bidder a little, but not too much.

Box 9 below discusses some of the 'tweaks' that were used in the Indian 3G and BWA auctions. There were two main issues that we were concerned about in designing these auctions.

First, not all of the existing 2G operators were present in all of the regional telecoms 'circles' for which licences were issued. In order to maximise competition *between* bidders, it was important to provide the means for bidders to expand beyond their existing territories if they so wished. This was made possible with provisions to allow bidding activity to be switched between circles. In order to avoid the risk that bidders would tacitly collude – sticking to particular geographical territories to avoid competition with rivals – there was limited transparency. In particular, it was not possible to see where exactly each bidder was bidding, only the total number of bids made in each circle. This measure to promote competition for spectrum would have been taken regardless of whether the objective was revenue maximisation or efficient allocation.

Second, there was a specific concern that in at least some circles the existing 2G operators might not face much competition at all, despite the measures discussed above. The potential problem was that winning prices would be determined by weak bids for those circles (somewhat like our previous discussion of why the Danish 3G auction was a sealed bid). To counter this, and to provide a further protection against

[17] For example, consider competition between symmetric bidders with independent private valuations. The revenue equivalence theorem tells us that we cannot increase revenue by giving up efficiency in this case. In this situation, an open auction and a first price sealed-bid auction are both efficient and at the same time maximize expected revenue.

tacit collusion, the closing rule for the auction exposed bidders to some risk of failing to win unless they increased their own bids even if no new bids were received from rivals in the relevant circle. As with a sealed bid auction, it was strong bidders enjoying significant surplus in some circles where there was little competition that were most affected by this rule. This created a small risk of an inefficient outcome in order to challenge strong bidders within circles with little effective competition.

BOX 9 – Design of the Indian 3G and BWA auction

The objective of maximising revenue had a number of implications for design of the Indian 3G and BWA auctions:

- The risk of unsold lots needed to be minimised;
- There were specific concerns about the strong position of 2G operators in some circles and whether they would be adequately challenged by rival bidders;
- Aggregation risks when acquiring licences across multiple circles should be kept low (though the large number of circles and the need for a relative simple auction precluded use of a combinatorial auction).

A number of further measures were put in place in order to encourage competition in the auction and to ensure that competition could not be dampened by tacit (or explicit) collusion amongst bidders:

- The lot structure meant that regional 2G operators could bid for 3G licences both in their respective areas of operation and outside these areas in order to extend their territories, with flexibility to shift bidding activity across circles;
- During the auction, bidders were only given information about their own bids and aggregate information about the number of bids received in each circle at the current price. This meant that regional operators could compete for lots outside their existing footprints without fear of explicitly retaliatory bidding on the part of other bidders, driving up the price of spectrum in the areas of their existing footprints in response to their competitive pressure elsewhere.

A requirement set by the government arising from Indian law was that all bidders winning substantially the same spectrum (e.g. a block of spectrum of a given size in the same band) must pay the same price. Given this requirement, a variant of the standard clock auction was selected for this award.

The auction proceeded in discrete rounds where the auctioneer announced a price per lot in each of the 22 telecoms circles. Bidders then stated their demand for lots in each circle at these prices. From round to round, the price of lots in oversubscribed circles increased. Rounds continued until there was no excess demand at current prices in any lot category. Activity rules were put in place to ensure that bidders could not increase demand as prices increased. Eligibility to bid in further rounds was set by a staged activity requirement; this reduced aggregation risks, as bidders did not initially need to bid for all circles of interest.

Unlike a standard clock auction, provisional winners and provisional winning prices were determined at the end of each round. The round price for a lot category was increased not only when there was excess demand for the lot category, but bids were also invited at a higher price if demand exactly matched supply.

Provisional winners for a lot category would win the lots in the category unless outbid in following rounds. The price to be paid by provisional winners was the lowest of the provisional winning bids on the lot category. In practice, this meant that bidders could be provisional winning bidders for lots in a given lot category at two different lot prices until the end of the auction.

Together with the closing condition, these rules had the implication that, once the activity requirement had been raised to 100%, bidders that were provisional winning bidders and whose provisional winning bid had been submitted at a price lower than the current round price were exposed to a risk of the auction closing in a round in which they had been outbid (without having the opportunity to come back with a higher bid). This rule encouraged bidders that were provisionally winning bidders in a lot category at a round price less than their valuation to place a bid at the following round price, as not doing so would be at the risk of losing lots in categories when prices were still at a level which they were willing to pay.

3.8 Reserve prices

We have said little so far about reserve prices. What role do these have for a government interested in revenue?

Reserve prices have a number of roles in spectrum auctions:

- they discourage frivolous participation;
- they might represent an outside option for the seller, as if spectrum does not secure a sufficiently high price at auction, it could be used for something else (e.g. public safety); and
- they can underpin revenue in the case that competition for spectrum is weak.

Consider, for example, the case in which there is one lot for sale and just one bidder applies to participate in the award. In this situation, the reserve price sets what the winner pays. However, suppose that two or more bidders participate given the reserve price set. In this case, prices will be determined by competition amongst those bidders. Therefore, reserve prices allow the seller to set a floor price specifically for the case in which there is just one bidder. For a seller, the optimal reserve price that maximises expected revenue is the take-it-or-leave-it offer that the seller would make to a *single* potential buyer.

The difficulty with setting reserve prices is that if they are to have much effect on revenues, then they must also run a risk of spectrum not being sold. For this reason, reserve prices are usually not a particularly effective tool to extract additional revenue from strong bidders facing weak rivals. The difficulty is that a spectrum authority will typically have relatively poor information about the likely valuation of winning bidders and not know at what point spectrum might just go unsold if reserve prices are set too high. Even if expected revenue is increased, this will come at the cost of an increase in the risk of the seller getting nothing in some cases. In practice, this risk means that reserve prices need to be set on a conservative basis relative to likely market value.

This again underlines the importance of making spectrum licences attractive to potential bidders to boost participation. High reserve prices are a poor solution to a situation in which competition for spectrum is likely to be weak due to underlying problems with spectrum licences or regulatory uncertainty. In practice, the most useful function of reserve prices in auction design is not as replacement for competition, but rather to limit the benefit for bidders from limiting the field of bidders (for example through pre-auction mergers) or through collusion and so discourage such behaviour.

4 Best practice for spectrum auctions

We have only lightly touched on some of the many complex issues that arise in auction design. Nevertheless, some clear messages for best practice can be identified from our discussion.

Efficiency and competition should be the key objectives

There are strong arguments that efficient allocation should be the overriding objective for spectrum allocation. Given the importance of services derived from spectrum for the wider economy, governments are typically best served by seeking to maximise the *overall* benefit to society from spectrum, rather than simply maximising receipts from spectrum sale in the short-run.

Efficient use of spectrum by competitive network operators encourages new services, ensures sufficient capacity for existing services and keeps prices down for customers. This generates direct benefits for consumers. Furthermore, services derived from spectrum are inputs into nearly every other sector of the economy. New services – for example mobile data - boost productivity. In the long run, this should boost output, from which a government earns revenue through general taxation over time in any case.

This said, efficient allocation of spectrum through a competitive process such as an auction inevitably raises revenue. Therefore, it is not necessarily the case that a government has to forgo significant short-term revenue to pursue an efficiency objective. Furthermore, where an efficiency objective is pursued, then auction revenues are a relatively 'clean' source of government revenue as, unlike general taxation, there is little distortion of economic decisions.

Revenue objectives must still protect competition

Where a government pursues a revenue maximisation objective, it should still work within the constraint that downstream competition in services derived from spectrum must be effective. Otherwise, this would lead to outcomes in which operators could gain market power downstream, raising prices for consumers who have little choice of alternative providers. In such a case, revenue would ultimately be generated at the expense of consumers and does not enhance the social value generated by spectrum.

In cases where competition for spectrum is vigorous, there may be little difference in practice between an auction design that maximises revenue (whilst ensuring effective downstream competition) and one that promotes efficiency. The two objectives are closely aligned in this case, with measures that promote efficiency typically increasing revenue and vice versa.

Key features needed for efficiency and revenue

There are certain features of a spectrum award process that need to be in place *regardless* of whether a government's objective is to achieve efficient allocation or maximise revenue:

- The rights and obligations associated with spectrum licences need to be clearly defined;

- There needs to be consistency and predictability in the actions of spectrum regulators, with commitment to stick to announced plans to avoid 'hold-up' of licensees;
- There should be reasonable predictability of any on-going charges made during the course of a licence;
- The rules of any auction process need to be clear, complete and consistent;
- The potential for competition for spectrum should be maximised, where possible allowing for flexibility in the amount of spectrum acquired by a bidder and the use ultimately made of the spectrum.

All of these features encourage participation in auctions and enhance competition for spectrum.

Revenue where competition for spectrum is weak

It is primarily in the case that competition for spectrum is weak that the objectives of revenue maximisation and efficient allocation may diverge. In such cases, then there may be 'tweaks' that can be made to auction designs to extract more value from winning bidders who might otherwise face little rivalry for spectrum. A situation that can arise in practice is where existing operators form the only strong bidders for a new spectrum band, with weak or non-existent competition from other parties.

These approaches typically trade off a *small* loss in the efficiency of outcomes to create greater competitive pressure on strong bidders and so raise revenue. It will always be difficult to extract a significant part of the surplus of strong winners in these situations. Therefore, it is important to have realistic expectations about revenue and not to create auction rules that create significant risks of grossly inefficient outcomes; ultimately such approaches tend to be bad for revenue also.

About DotEcon

DotEcon Ltd provides strategy and consulting advice to networked industries. Our services include:

- regulatory advice;
- design of auctions or trading mechanisms and bidder support;
- economic and market analysis in competition cases and commercial litigation;
- public policy design and impact assessments;
- demand modelling, including econometric analysis of customer data, and development of pricing tools;
- business strategy and decision support.

DotEcon is the leading global supplier of design and build services for complex, high-value auctions. We have designed and implemented many auctions for radio spectrum around the world, in including Hong Kong, India, the Netherlands, Norway, Sweden and the UK. DotEcon designed and implemented the novel clock auction that has been used by Ofcom for all recent UK spectrum auctions.

DotEcon advises bidders in major auction transactions around the world. We have supported auction bidders in radio spectrum auctions in more than a dozen countries across Europe, the Americas and Asia Pacific.

DotEcon provides a one-stop shop for all aspects of designing and running auctions. We have developed a suite of auction software tools to implement auctions, test bid strategies and visualise dynamic auctions. Our WebBidder™ auction software provides best-in-class secure deployment of complex auctions for high-value transactions. It allows rapid prototyping and experimental testing of new and novel auction formats. It has also been used extensively by governments around the world for radio spectrum auction sales running into many billions of dollars.

About the author

Dr Dan Maldoom is a Partner of DotEcon Ltd, which he co-founded in 1999. He was previously Fellow and Tutor in Economics at University College, Oxford.

He advises governments around the world on auction design and the use of market mechanisms. He is currently advising Ofcom on the UK's forthcoming 4G auction. In 2010, he advised the Indian government on the design and implementation of its successful 3G auction. He has been responsible for the development and now widespread adoption of combinatorial auctions for spectrum across Europe and beyond.

He also has advised many private clients involved in high value auctions and negotiations. He has also been involved with many high profile and contentious competition and regulatory cases in the telecoms sector in front of the UK and EU courts.