Auction Design Issues for Spectrum Awards

Market Analysis Ltd

March 2006

1. Optimality of Auctions

There is widespread agreement among economists that auctions are the best way to allocate scarce spectrum resources, and auctions have now become the preferred method of assigning spectrum in many countries. Auctions provide an answer to the basic question 'Who should get the licenses and at what prices?'[1] Alternatives to auctions are an administrative process ("beauty contests") or lotteries. Both alternatives have been used and then rejected in the US, Europe and elsewhere.

The primary advantage of an auction is its tendency to assign the spectrum to those best able to use it. This is accomplished by creating competition among license applicants. Those companies with the highest value for the spectrum are willing to bid higher than the others, and hence tend to win the licenses. There are many subtleties that limit the efficiency of spectrum auctions, but a well-designed auction can be highly efficient. A second important advantage of auctions is that the competition is not wasteful. The competition leads to auction revenues, which can be used to offset distortionary taxation. Finally, an auction is a transparent means of assigning licenses: all parties can see who won the auction and why.

Since the mid-1990s, the United States has relied on auctions to award spectrum. Many countries in Europe, as well as Australia, New Zealand, Canada, Mexico, Brazil, and India, have also used auctions in the last ten years. The approaches taken have varied from country to country, and within a country from auction to auction. With some notable exceptions, the most common approach has been the multi-round simultaneous ascending auction (SMRA), adopted by the FCC.[2] Even within this broad format, many alternative versions have been used, and these differences can play an important role in an auction's success.[3]

---

1 Ronald Coase proposed auctioning spectrum over forty years ago, but it was not until 1994 that auctions for spectrum were first used in the US.

2 One exception was the successful Danish spectrum auction in 2001, which was a uniform-price, sealed-bid auction. Another is Ofcom's proposed sealed-bid 'menu auction' for the 1781.7-1785 MHz and1876.7-1880 MHz bands.

3 See "Overview of the European Auctions," Chapter. 5 of P. Klemperer, *Auctions: Theory and Practice*, Princeton University Press, 2004, for a discussion of differing designs in the first

2. Objectives of Spectrum Auctions

Spectrum auctions typically involve the sale of multiple, interrelated licenses. We have only begun to understand such auctions in theory and practice. There are neither strong theoretical nor empirical results to guide the design of spectrum auctions in practice, although there is now considerable accumulated experience to learn from. Nevertheless, designing spectrum auctions remains as much art as it is science.

The objectives of most spectrum auctions are three-fold. A primary goal is efficiency—allocating the spectrum to those who value it most and are best able to use it. An equally important goal is creating, sustaining, or increasing downstream competition for spectrum-based services. This goal can come into conflict with the efficiency objective, as allowing for some inefficiency in the auction design may be necessary to induce or encourage participation by new entrants.[4] A third goal is revenue maximization. Since auction revenues are less distortionary than the principal source of government revenues – taxation – governments should not be indifferent to the amounts raised by spectrum auctions.

It is sometimes suggested that efficiency is not an important objective if resale or secondary trading is allowed after the auction. This assumes that post-auction transactions will correct any auction-related inefficiencies. While this may be true in a Coasean world without transaction costs, in the real world transaction costs are not zero. In general both buyers and sellers of spectrum have private information about their valuations. In any bargaining process, sellers have an incentive to overstate their valuation and buyers to understate theirs.[5] Post-auction transactions often are made difficult by strategic behavior between parties with private information and market power. Hence, while efficient auctions are possible before assignments are made, they may become impossible after an initial assignment.[6] Secondary trading is therefore not a panacea to correct inefficient outcomes created by poor initial spectrum assignments.

---

round of spectrum auctions in Europe, and how these differences may have influenced the outcomes.

4 This was the idea behind the design of the Anglo-Dutch auction. See P. Klemperer (2002), "What Really Matters in Auction Design," *Journal of Economic Perspectives*, Vol. 16, for a discussion.

5 The Myerson-Satterthwaite theorem states that under these conditions, no bargaining process attains efficiency with probability one. The designers of the UK's 3G auction, Ken Binmore and Paul Klemperer, have similarly stated that "allowing resale is not a perfect substitute for an efficient allocation because resale does not resolve all inefficiencies." K. Binmore and P. Klemperer (2002), "The Biggest Auction Ever: The Sale of the British 3G Telecom Licences," *Economic Journal,* 112.

6 See P. Cramton, R. Gibbons and P. Klemperer, "Dissolving a Partnership Efficiently," *Econometrica*, 55, 615-632, 1987.

3. Auction Design Issues

A number of broad issues need to be considered in the design of any particular spectrum auction. Three of the most important are:

1. Do bidders face significant uncertainty concerning the value of the spectrum in any particular use?
2. Are there incumbent bidders with market power, and hence a need to discourage collusion or to encourage new entry?
3. Are the different licences or units of spectrum up for auction, substitutes or complements for the bidders, or both?

3.1. Open versus sealed-bid auctions

An essential advantage of open bidding is that the bidding process reveals information about buyers' valuations. This information promotes the efficient assignment of licenses, since bidders can condition their bids on more information. Moreover, to the extent that bidder values are affiliated, it may raise auction revenues, since the winner's curse is reduced.[7] Bidders are able to bid more aggressively in an open auction, since they have better information about the item's value. Thus if bidders are uncertain about the (common) value of the spectrum, and face the winner's curse, open bidding procedures are recommended.[8]

An advantage of a sealed-bid design is that it is less susceptible to collusion (Klemperer, 2002, *op. cit.*). Open bidding may allow bidders to signal through their bids and establish tacit agreements. With open bidding tacit agreements can be enforced, since a bidder can immediately punish another that has deviated from a collusive agreement. Signaling and punishments are not possible with a simultaneous sealed-bid auction. Collusive concerns are also of stronger practical importance in multi-unit auctions than in single-unit auctions. Collusion is easier to sustain with multiple units as bidders may find it easier to divide the spoils.[9]

---

[7] P. Milgrom and R Weber, "A Theory of Auctions and Competitive Bidding," *Econometrica*, 50, 1089-1122, 1982.

[8] In most spectrum auctions we would expect bidders to have common or affiliated valuations, or 'business cases', however often with significant uncertainty concerning say, the demand for services they can expect.

[9] See M. Pesendorfer (2000), "A Study of Collusion in First-Price Auctions," *Review of Economic Studies*, 381-411, for this result.

A second advantage of a sealed-bid auction is that it may encourage entry, by giving weaker bidders at least some chance of winning the auction (Binmore and Klemperer, 2002, *op. cit*.). This can also result in higher revenues when there are ex ante differences among the bidders.[10] This is especially the case if the bidders are risk averse, or budget constrained.[11] In a sealed-bid auction, an incumbent bidder can guarantee victory only by placing a very high bid, whereas in an open auction a strong bidder never needs to bid higher than the second-highest value.

In most spectrum auctions held to date there has been a consensus in favor of open bidding. The advantage of revealing more information in the bidding process has been thought to outweigh any increased risk of collusion. One exception is the 2001 Danish spectrum auction in which encouraging bids by a single new entrant, and discouraging collusion amongst the incumbents, were viewed as crucial criteria, leading to the choice of a sealed-bid format.[12] Another was the proposed 'Anglo-Dutch' auction for the UK 3G auction, although it was never used. The idea behind this auction design was to obtain the best of both worlds by following an initial open-bidding phase with a single round of sealed bids.[13] More recently, Ofcom is proposing to hold a sealed-bid 'menu' auction for the former 'guard bands' based on precisely these considerations.[14]

3.2. Individual or combinatorial (package) bids?

A bidder's valuation of a license may depend on the other licenses it acquires. In the presence of complementarities, allowing bidders to convey information about their values for the combinations of licenses, in addition to their value for the individual licenses, is a necessary condition for efficiency. Not allowing package bids can create inefficiencies by forcing bidders to "hold back" for fear of acquiring licenses at prices higher than their individual value. From the bidder's perspective, placing individual bids

---

[10] Asymmetries between bidders are particularly important in spectrum auctions in which entrants compete against incumbent bidders. See E. Maskin J. and Riley (2000), "Asymmetric Auctions", *Review of Economic Studies*, 67(3), pp413-438; also P. Klemperer (1998), "Auctions with Almost Common Values: The 'Wallet Game' and its Applications", *European Economic Review*, 42(3-5), 757-769.

[11] E. Maskin and J. Riley (1984) "Optimal Auctions with Risk Averse Buyers," *Econometrica*, 52, 1473-1518; and Che, Y.-K., and I. Gale (1998), "Standard Auctions with Financially Constrained Bidders," *Review of Economic Studies, 1-21.*

[12] If possible, it is often preferable to pre-allocate a licence or licences to new entrants, rather than forsake the advantages of open bidding procedures, as was ultimately done in the UK 3G auction.

[13] The Anglo-Dutch auction is described in Binmore and Klemperer, 2002, *op. cit*. This auction design is currently being used to allocate virtual power plant capacity in Denmark

[14] Ofcom, "Award of available spectrum: 1781.7-1785 MHz paired with 1876.7-1880 MHz: A Consultation," 16 September 2005.

can fail to achieve the desired goal as a bidder may fail to acquire some parts of the desired combination. This is *the exposure problem*. Individual bidding exposes bidders seeking complementary combinations of licenses to aggregation risk.

A combinatorial auction addresses this inefficiency. But allowing package bids can create other problems. The theory of optimal bidding in combinatorial auctions is still in its infancy, and their performance is not well-studied. Even in the case of perfect information,[15] there can be multiple equilibria, and the equilibrium outcomes may be inefficient or may allow advantaged bidders to obtain licenses for prices well below their valuations.[16]

One well-understood problem with combinatorial auctions is that package bids may favor bidders seeking large aggregations due to a variant of the free-rider problem, called "the threshold problem".[17] Indeed, Cantillon and Pesendorfer (2006), *op. cit.*, show that combination bidding may reduce auction revenues when only one (or a few) bidders wish to acquire multiple units.

A key problem with combinatorial auctions is their complexity. If all combinations are allowed, even identifying the revenue maximizing assignment can be an intractable integer programming problem (the "winner determination problem"). And as Milgrom (2004) has pointed out, the winner determination problem 'makes it hard for bidders in a combinatorial auction to forecast the consequences of their bids.' The calculus of bidding is much more involved with package bids. These problems can be sometimes be alleviated by restricting the set of allowable combinations. However, these restrictions may themselves introduce inefficiency by eliminating many desirable combinations.

Equally difficult may be the "valuation determination problem." With no restrictions on the number of package bids, even fairly small auctions can lead to there being an infeasible number of combinations to be valued. For example, with the twelve licenses envisaged for sale in the postponed FCC Auction 31, each bidder would in principle need to consider his valuation for each of 4095 distinct combinations involving between one and twelve licenses. A standard assumption in auction theory is that each bidder knows all its values or can compute them at a zero cost. For package auctions, the

---

15 See Chapter 8 of P. Milgrom (2004) *Putting Auction Theory to Work*, Cambridge University Press. Also, D. Bernheim, and M. Whinston (1986) "Menu Auctions, Resource Allocation and Economic Influence," *Quarterly Journal of Economics*, 101, 1-31.

16 See E. Cantillon, E. and M. Pesendorfer (2006) "Auctioning Bus Routes: The London Experience," in P. Cramton, Y. Shoham and R. Steinberg (eds), *Combinatorial Auctions*, MIT Press.

17 See M. Bykowsky, R. Cull and J. Ledyard (2000) "Mutually Destructive Bidding: The FCC Auction Design Problem," *Journal of Regulatory Economics*, 17.

sheer number of combinations that a bidder must evaluate makes that assumption dubious.[18]

Increased complexity is a legitimate concern when considering package bids. Although simultaneous auctions with package bids were successfully tested in the laboratory (Bykowsky et al. *op. cit.*), it is far from certain that successful combinatorial auctions can be run except in simple cases with few licenses. One solution, already provisionally adopted by the FCC, is to place restrictions on the combinations of licenses which may be bid for, but the threshold problem and the increased complexity of package bidding first needs to weighed against the likely inefficiency created by the exposure problem.[19]

3.3. Sequential or simultaneous auctions?

Sequential auctions limit the information available to bidders, and also how the bidders can respond to information. In a sequential auction a bidder must guess what prices will be in future auctions when determining bids in the current auction. Incorrect guesses may result in an inefficient assignment when license values are interdependent.[20] Sequential auctions also eliminate many strategies. A bidder cannot switch back to an earlier license if prices are high in a later auction. Hence bidders may regret having purchased early at high prices, or not having purchased when prices were low. This guesswork about future auction outcomes makes strategies in sequential auctions complex, and the outcomes less efficient.[21]

Proponents of sequential auctions argue that the relevant information for the bidders is the final prices and assignments, and that a sequential auction gives final information about prices and assignments for all prior auctions. They also point out that the great flexibility of a simultaneous auction makes it more susceptible to collusive strategies.

---

[18] See L. Ausubel and P. Milgrom (2002) "Ascending Auctions with Package Bidding," *Frontiers of Theoretical Economics,* Volume 1, Issue 1. The case for open auctions is potentially strengthened when it is costly for bidders to determine their preferences. A dynamic auction, by providing tentative price information, can reduce these costs for bidders.

[19] The report by DotEcon and Analysys/Mason Group (2005) proposed that a combinatorial auction be used for allocating the 2010-2025 MHz and the2290-2302 MHz bands. However, the report did not specify a detailed auction design. Evidently simple combinatorial auctions were used for spectrum allocation in Nigeria, but it is difficult to evaluate their success. Not all of the licences were sold, and five of the winning bidders defaulted, suggesting at least that deposits were set too low.

[20] See especially M. Jofre-Bonet, M. and M. Pesendorfer (2003), "Estimation of a Dynamic Auction Game," *Econometrica,* 71(5), 1443-1489.

[21] In the Swiss wireless-local-loop auction conducted in March 2000 provides an example of this problem. Three licenses were sold in a sequence of ascending auctions. The first license sold for 121 million francs, the second for 134 million francs, and the larger third license for 55 million francs. Hence the largest license sold for less than half the price of the smaller licenses achieved in the earlier auctions.

Since nothing is assigned until the end in a simultaneous auction, bidders can punish aggressive bidding by raising the bids on those licenses desired by the aggressive bidder. In a sequential auction, collusion is more difficult to sustain.

Ofcom has recently taken the view, at least where licenses are perfect substitutes, that the danger of exposing bidders to 'substitution risk' weighs heavily in favour of simultaneous as opposed to sequential auctions.[22]

3.4. Alternative auction pricing rules

A variety of pricing rules are possible in both sealed-bid and open auction formats, including most importantly: [23]

1. A uniform pricing rule in which the winners pay the price of the lowest winning bid.
2. A 'pay as bid', or discriminatory, pricing rule in which bidders pays the amount bid for each unit won.
3. A Vickrey pricing rule in which winners pay the 'opportunity cost' of their bids (typically the highest losing bid which a given winning bid has 'displaced').

Both uniform and discriminatory auction are commonly used in financial and other markets, and there is now a large economic literature devoted to their study.[24] In multi-unit settings (such as in auctions for spectrum), the comparison between these two auction forms is particularly complex. Neither theory nor empirical evidence tell us that discriminatory auctions perform better than uniform auctions in such environments.

One potential disadvantage of discriminatory pricing is that bidders may pay very different prices for identical objects (i.e. licenses). Many bidders dislike this sort of price variation when licenses are homogeneous. However, a 'pay as bid' auction may reduce the disadvantages faced by 'weaker' bidders, as 'strong' bidders may be encouraged to bid more aggressively by a uniform-pricing rule (Maskin and Riley, 2004, *op. cit.*; also Ofcom, 2005, Ch. 8).

It is sometimes argued in favour of uniform pricing –and especially Vickrey pricing – rules that they reduce the strategic complexity of the auction for bidders, making 'straightforward' bidding a more profitable strategy. In a uniform-price auction, small bidders can simply bid their valuations and be assured of paying only the market-clearing price. Such a strategy is not optimal for bidders with market power, however.

---

22 Ofcom, "Award of available spectrum: 1781.7-1785 MHz paired with 1876.7-1880 MHz: A Consultation," 16 September 2005.

23 See the discussion in Ofcom, 2005, *op. cit.*, Chapter 8.

24 N. Fabra, N.H. von der Fehr and D. Harbord (2006) "Designing Electricity Auctions," *Rand Journal of Economics* (forthcoming); and K. Binmore, K. and J. Swierzbinski (2000) "Treasury Auctions: Uniform or Discriminatory?" *Review of Economic Design*, Vol. 5, pp. 387-410, contain recent discussions of the theory and empirical evidence.

One perceived problem with uniform-price auctions is the existence of multiple equilibria, some of which result in very low prices.[25] While a theoretical possibility, especially in continuous auctions, it is not clear that this problem arises in most practical applications.[26]

Under Vickrey pricing (including Vickrey-Clarke-Groves mechanisms), it is a dominant strategy for each bidder to bid his valuation, so 'strategic uncertainty' or the 'fog of war' is eliminated from the auction, ensuring efficient allocations. While this is frequently considered to be a decisive factor in theory, Vickrey auctions are rarely if ever used in practice for assigning multiple units. Some reasons for this are discussed in Milgrom (2004), *op. cit.*, Ch.'s 2 and 8.

4. Spectrum Packaging and Technological Neutrality

The way the spectrum is packaged, and the potential business uses to which it can be put, are key considerations in determining an efficient auction design. For instance, DotEcon has recently recommended packaging the 2010-2025 MHz and the2290-2302 MHz bands into three and two blocks of 5MHz nationwide units respectively, and holding a single sealed-bid combinatorial auction for them. A wide variety of services and technologies were identified as potential users, including mobile data, fixed wireless broadband, and vision carriers for programme makers.[27]

Consideration was then given to combining the 2010-2025 MHz and the 2500-2690 MHz bands in a single award process, making the number of potential blocks or units potentially unmanageable for the purposes of holding a combinatorial auction, without placing significant restrictions on the number of packages which may be bid for.[28] Thus the amount of spectrum available for simultaneous sale, and the likely efficacy of imposing bidding restrictions on packages, play an important role in the auction design.

A second consideration relates to Ofcom's criterion of technological neutrality. In principle this should maximise the number of uses to which the spectrum can be put, and hence its potential economic value. However, if there are significant costs associated with the sharing of adjacent blocks of spectrum by different technologies, these may have an impact on the efficiency of an auction. Indeed, interference or the

---

[25] See Klemperer (2002), *op. cit*. and Milgrom (2004), Ch. 7, for discussions.

[26] See Fabra, von der Fehr and Harbord (2006), *op. cit.*, for a recent discussion; also I. Kremer and K. Nyborg (200) "Underpricing and Market Power in Uniform-Price Auctions." *Review of Financial Studies*, 17: 849-877.

[27] *Allocation Options for Selected Bands*, Final report for Ofcom prepared by DotEcon and Analysys Mason Group, February 2005.

[28] If there are *n* units for sale, the number of combinations is 2^n-1, clearly an enormous number if all three bands were split into 5MHz units and auctioned simultaneously.

need to provide guard bands may mean that no *straightforward* auction of the licences will guarantee either an efficient allocation of the spectrum or maximise seller revenue.[29]

To see the issues in their simplest form, consider the following table of valuations for spectrum licences. Assume there are two licences, L1 and L2, and four bidders. Bidders 3G1, 3G2 and 3G3 require the spectrum for 3G use and if these bidders acquire both licences there will be minimal interference. The fourth bidder, "WiMax", plans to use the spectrum for a different purpose that creates a larger amount of interference with 3G users. The effect of interference is to lower the valuations of the 3G bidders, since sharing the band with an alternative technology exposes them to additional costs (such as filtering or provision of 'guard bands') to control interference.

	Sole 3G use		Mixed use	
	L1	L2	L1	L2
3G1	10	11	6	7
3G2	11	10	7	6
3G3	10	10	6	6
WiMax	-	-	10	12

If we assume these valuations are common knowledge, and that each bidder may acquire only one licence, it is easy to see that a simultaneous multi-round ascending auction (SMRA) will assign licence L2 to WiMax at price of 7 and L1 to 3G2 at price 6. The total auction revenue is 13 and the value of the assigned spectrum to its users is 19. However, it would be preferable to restrict the spectrum to sole 3G use. If this were done, an ascending auction would assign licence 1 to 3G2 and licence 2 to 3G1, each at a price of 10. The auction would realise revenues of 20 and a total value of 22. Thus opening up the expansion band to multiple uses can result in an inefficient allocation of spectrum.

Allowing (bilateral) secondary trading would not resolve this inefficiency. No 3G bidder is willing to pay 12 to acquire licence 2 from Wimax, the minimum that Wimax would accept. It would require a coalition of 3G2 and another 3G bidder to raise sufficient funds to purchase L2 from Wimax.

Similarly, a technology-neutral approach cannot be guaranteed to group spectrum in a way that minimises the costs of interference. To see this consider again an auction for a

---

[29] "Straightforward" in this sense is some form of open ascending auction of a type similar to that used to assign the existing 3G licences.

number of licences with each bidder restricted to acquiring a single licence.[30] Bidding continues so long as there are more active bidders than licences, and stops when the number of active bidders equals the number of licences. The number and behaviour of the unsuccessful bidders, however, limits the ability of the auction mechanism to efficiently allocate licences amongst successful bidders, and efficiency is not guaranteed when bidders value licences differently according to whom their immediate neighbours in the spectrum are.

The following example illustrates this point. There are three licences and four bidders. One bidder is a "weak" bidder on all licences, and never wins a licence. There are two 3G bidders who value the licences more if they both win adjacent licences. The WiMax bidder has different preferences; it prefers to separate the 3G bidders.

	Separated Licences			1-2 Adjacent			2-3 Adjacent		
	L1	L2	L3	L1	L2	L3	L1	L2	L3
3G1	6	-	7	10	11	-	-	11	10
3G2	7	-	6	11	10	-	-	10	11
Weak Bidder	6	6	6	6	6	6	6	6	6
WiMax	-	13	-	-	-	7	7		

In the SMRA auction, bidding will proceed until the weak bidder is priced out of all licences and then the stop. The price on each licence will be a minimum of 6 at this point (the weak bidder's valuation for each of the licences). The efficient allocation of licences is clearly either having licences 1-2 adjacent or licences 2-3 adjacent. The total surplus is then 11+11+7=29 compared with 13+7+7=27 for separated licences. However, there is no equilibrium that achieves an efficient outcome. WiMax obtains at most a profit of 1 in that allocation, but can guarantee profit at least 2 by bidding solely on licence 2 until the other bidders drop out. Again, bilateral secondary trading would not resolve this inefficiency since no losing bidder would be willing to pay 13 to acquire L2 from Wimax.

The preceding two examples show that in the presence of interference, standard auction mechanisms cannot be guaranteed to result in an efficient allocation of spectrum, and that prior constraints, such as limiting spectrum bands to particular uses or technologies,

---

30 This was the situation for the UK 3G auction in which bidders could only bid on one licence at a time and were not allowed to switch bids while current high bidder on a licence.

may be worth considering.[31] Of course, a potential cost of doing so is that the spectrum may not be awarded to the companies or technologies that value it most. Whether a technology-neutral approach is to be preferred on efficiency grounds will likely depend on the size of the costs which interference actually imposes on potential bidders, and also on the ‘homogeneity’ of the spectrum from the bidders’ point of view. For example, if bidders care only about acquiring certain aggregate quantities of spectrum, but not the precise bands, then the auction allocation process itself might be designed to minimise interference costs. Homogeneity also simplifies the problems involved in holding a combinatorial auction. If all licences are perfect substitutes, but at least some bidders wish to acquire aggregations of licences, they can submit bids 1,2,3, … licenses etc., without needing to specify <u>which</u> licenses these are.

[31] We have already noted above that secondary trading is not a panacea to correct inefficient outcomes created by an initial poor spectrum allocation.