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Inter-Regional Firm Access Auction Design

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1. THE TASK

I have been engaged by the Australian Energy Market Commission to provide high level advice on auction design for the allocation of inter-regional firm access rights. As will be clear from the analysis below, auction design entails a number of interrelated choices, each influencing the format of the auction.

Therefore, rather than recommending a particular auction format, this report will focus on auction design principles (e.g., product definition, auction objective, static versus dynamic auctions, how to set reserves, etc.) and canvass different auction formats.

Nevertheless, the report provides a description of a particular auction format, and an associated product definition, that could be used to allocate firm access rights. The particular format is meant to illustrate how an auction for firm access might work, the underlying choices that need to be made, and the relationship between these choices and the auction format. The report also provides some underlying reasons why a static NEM-style auction may not be appropriate for allocating firm access rights.

Ultimately, however, the chosen auction format will need to be determined by further investigating alternative auction formats, and associated rules, including extensive laboratory testing. To this end, the report expounds the various practical steps typically associated with auction design.

In preparing this report, I have reviewed two OFA Discussion Papers produced by AEMC staff on inter-regional access auctions (dated 11 June 2014 and December 2014), and The Transmission Framework Review Final Report, and have had a number of discussions with AEMC staff (including consultant Dave Smith). I understand that this report will be incorporated into a Draft Report on OFA to be published on the AEMC's website.

2. WHY AUCTIONS?

Auctions have emerged as the preferred approach to the allocation of many resources, including radio frequency spectrum, electricity, timber, and – most relevantly – financial electricity transmission rights.[1]

A well-designed auction dominates other potential mechanisms (such as bilateral bargaining) in its ability to allocate resources to parties with the highest valuation. A well-designed auction is also better able to meet efficiency objectives such as ensuring that investment in transmission capacity is undertaken whenever it is worthwhile – that is, whenever the value associated with expanding capacity is greater than or equal to the cost of the capacity expansion.

An important reason why a well-designed auction is desirable in this instance is related to the existence of asymmetric information. While the costs of the capacity expansion may be reasonably known to the transmission companies, they do not know the value that generators (and other parties) place on being able to dispatch electricity in an unconstrained matter. Bids in a well-designed auction are related (but not necessarily identical) to the values that buyers assign to the object or right on sale. For example, in a well-designed auction bidders with higher values submit higher bids, ensuring the object is allocated to the bidder who values it the most. In contrast, in bilateral negotiations, there is no guarantee that the parties negotiating have the highest value for the asset.[2] This suggests that a priori, a well-designed auction is preferred to negotiations as an allocation mechanism for inter-regional firm access rights.

However the emphasis on the expression “well-designed” should not be underestimated. Auctions operate in environments where competitive markets do not work and, as a result, individual behaviour may adversely impact market outcomes. Thus, the “well-designed” expression embodies the notion that the auction mechanism and associated rules are designed with a view to incentivise bidders to behave in a way that is consistent with the overall (efficiency) objective of the auction. While economic theory provides guidance on many design issues, laboratory testing plays a crucial role in identifying rules that can be exploited by bidders and may lead to adverse outcomes.

[1] For an introduction to the theory of auctions, see F. M. Menezes and P. K. Monteiro, 2008. *An Introduction to Auction Theory*, Oxford University Press, and for an extensive review of the theory and application of auctions to public policy see Milgrom, P. 2004. *Putting Auction Theory to Work*, Cambridge University Press and Klemperer, P. 2004, *Auctions: Theory and Practice,* Princeton University Press.

[2] More formally, it can be shown that under some reasonable conditions, a simple auction with N + 1 competitors dominates a negotiation game between a seller and N potential buyers. See Bulow, J. and Klemperer, P. 1996, “Auctions Versus Negotiation”, *American Economic Review*, vol. 86 no. 1, pp. 180-193, who compare the expected revenue between the two mechanisms.

3. HOW AUCTION DESIGN WORKS IN PRACTICE

The standard approach employed to design a market institution (such as an auction) to allocate a right or a good is referred to as market design.[3] It comprises two distinct dimensions:

- **The institutional framework** – This includes the institutions and constraints that are exogenous to the design of the auction. For example, it encompasses the structure of the industry (e.g. vertical separation, and the location of generators and the type of fuel they use), the overarching regulatory and institutional framework (e.g. the operation of the wholesale electricity market, the price setting mechanisms for distribution and transmission, and the nature of competition in retail electricity markets), and the characteristics of the objects or rights for sale (e.g. whether they are substitutes or complements, and whether rights give rise to common costs).
- **The auction mechanism** – This includes the specification of the conditions of use of the object or rights being auctioned off, including their transferability to third parties, how bids are submitted and how those bids are used to allocate the rights, how to set reserve prices and the payments which occur at the end of the auction.

Auctions are an institution that allows the seller of a right to design the rules that will apply to the allocation of that right. The design of the auction mechanism involves three interrelated steps:

- The definition of the product/rights to be auctioned off – in the case of inter-regional firm access rights this includes: the "shape" of the allocation (e.g. a constant annual MW, and the number of years); the location (e.g. each directed interconnector (DIC), in each direction); and also the post-auction regime which includes payment rules, the tradability of rights and whether successful bidders can use future auctions to on sell their rights.
- Allocation methodology – this step relates to choosing the basic design settings: whether to sell rights sequentially or simultaneously; to use a dynamic or a static auction; how often to run the auctions; how to allocate the rights and at what price; what information policy should be used; and how to set reserve prices.
- Auxiliary rules – the third step involves: defining activity rules (see Section 5.3.1 below); specifying what happens if bidders default; determining how unallocated capacity will be re-auctioned in the future; and stipulating how payments should be made (e.g. upfront versus deferred until expansion is undertaken).

[3] For an introduction to market design, see F. M. Menezes, "Market Design for New Leaders", Australian Public Policy Discussion Paper, 2013. Available at http://ageconsearch.umn.edu/bitstream/159194/2/WP13_4.pdf.

The optimal choices in each of the steps will depend on a range of considerations including the objective of the auction, the nature of bidders' valuations, and the structure of the industry including the specific characteristics (e.g. physical properties) of the electricity sector.

3.1 Auction objectives

Economic efficiency – allocating the existing capacity to bidders with the highest valuation (allocative efficiency) and ensuring that capacity is expanded whenever it is efficient to do so (dynamic efficiency) – is usually a key criterion for designing an auction as an allocation mechanism.

Unlike in many settings where the government is allocating a right, maximising revenue should not be a consideration in the allocation of firm access rights. This implies that there is no potential trade-off between maximising revenue and efficiency, and the objective of the auction is solely to ensure allocative and dynamic efficiency. [4]

It is worth pointing out why economic efficiency may be a more appropriate auction objective than maximising volume subject to auction revenue covering access cost, as proposed in the Discussion Paper. The reason is that maximising volume (total MWyears) may result in an inefficient allocation. It is conceivable that the total auction revenue covers the cost of providing access, but that the auction mechanism results in bids that deviate from valuations in such a way that maximising volume yields inefficient outcomes, where some bidders may purchase too much access from a social viewpoint and others too little.

The focus on efficiency has implications for the auction allocation rules: it suffices for the auction design to ensure that the auction revenue is enough to cover the efficient costs of expanding capacity whenever bidders value the expansion more than its cost.

3.2 The nature of bidders' valuations

Auction design is also influenced by the structure of bidders' values. For example, a generator's valuation of firm access might have an idiosyncratic (private) component that depends on its location vis-à-vis the network. Bidders' valuations may also have a common component, regardless of whether bidders are generators, retailers or investors, reflecting the post-auction

[4] For example, revenue maximisation in an auction can be implemented by setting a reserve price above the seller's value for the object on sale. This, in general, can lead to more aggressive bidding, resulting in higher revenue than in the case when the reserve price is set at the seller's value. However, this can lead to an inefficient allocation when the object is passed in even though the highest value bidder has a valuation greater than the seller's value but below the reserve price.

value of the right which can be resold. This ex-post common value is usually unknown at the time of the auction; bidders only have estimates of the common value from estimates of future demand, past bid patterns in the wholesale market and other relevant information.

The structure of values has a direct impact on the choice of auction mechanism. For example, when bidders value firm access rights over different interconnectors, a simultaneous sealed-bid (static) auction can lead to exposure problems; a bidder for whom rights are substitutes or complements might be very cautious in submitting bids for multiple rights for fear of winning ”too many” or the “wrong” combination of rights. In this instance a dynamic auction mechanism (such as a simultaneous multi round auction with or without combinatorial bids or a clock auction as described below) may be more appropriate. In contrast, a simultaneous sealed-bid auction[5] might perform well when a bidder's values for various rights are independent or when bidders want access rights to a single interconnector.

In the case of inter-regional transmission rights, it seems that rights may be independent for at least a subset of bidders. For example, a generator might be interested in acquiring a particular strip (a number of MW for a particular year) for a specific DIC. However, other players such as national electricity retailers may be interested in acquiring rights across a number of DICs and these rights may be substitutes or complements.

3.3 Industry structure

Industry structure is also an important consideration. For example, consider a setting where there is a large bidder (or bidders) with “deep pockets” and a number of smaller bidders. The latter might simply not enter a dynamic auction as they know they can be outbid by the larger bidder. As a result, a dynamic auction may lead to inefficient outcomes over time. In such a case a sealed-bid auction might increase the likelihood of participation by small players as they face a positive (albeit perhaps small) probability of winning.

The structure of the industry can also affect the likelihood of collusion (tacit or otherwise) and impact design decisions on the choice of reserve prices. The next sections discuss product definition and choice of the auction format in more detail.

[5] While it is possible to allow bidders to submit bids for combinations of rights at various interconnectors, in practice the strategic problem of determining what combinations are best at which prices from the viewpoint of a bidder, in the absence of feedback about how other bidders value the various combinations, becomes very complex.

4. PRODUCT DEFINITION

The first step in designing an auction is to define the nature of the objects to be sold. This includes issues of size and location (e.g. 1 MW of firm access at a particular DIC) and of timing and temporal aggregation (e.g. annual allocation of existing capacity and less periodic allocation of new capacity for a year ahead or for several years ahead). The nature of the asset and the associated legal entitlements are also important: whether it is existing or new capacity, and whether resale is possible or the right is use-it-or-lose-it (such as a take-or-pay contract).

The nature of the rights being sold has implications for auction design. For example, if the rights are defined as small units (e.g. 1 MW at a particular DIC for a year), then these units are to be aggregated through the auction process and this should result in the combination of units awarded to each participant more closely reflecting their values than if larger units (e.g. blocks of 20 MW) were administratively aggregated before the auction. The auction design must, therefore, allow and facilitate this aggregation and price discovery.

As product definition is an integral part of the design process, it requires considered analysis. In this section we review the different decisions that need to be made when defining a product, and comment on how these decisions flow through to design.

4.1 Size and Location

As a general proposition, the rights should be divided into the smallest units for the purposes of allocation, as long as the auction process does not unduly constrain the ability of bidders to secure their preferred combination of units. The reason is that the smaller the units, the more accurately bidders are able to define the particular combination of units that they value the most. As an additional benefit, more small bidders with high valuations may be able to participate in the auction if units are small.

In the case at hand, the smallest unit from a practical viewpoint seems to be one MW at a particular DIC (and in a particular direction). However, feedback from industry on this question should be sought. To this end, it is important to note that choosing a unit as small as a MW has implications for the choice of the auction format (typically a dynamic auction) as the auction must effectively facilitate the aggregation of units to match bidders' preferences.

4.2 How much to allocate in each auction, how often auctions should be held and what the duration of the rights should be

Provided that there is sufficient existing capacity and/or the prospect of demand for new capacity to offset the administrative costs imposed on participants and government from running the auction, timing – or how often to approach the market – is a policy decision. There is, however, some guidance given below to inform such a decision.

When there are a known number of objects for sale, the general principle is that it is best to sell them all at once, simultaneously, rather than through sequential sales. The key reason is that selling sequentially creates an exposure problem; bidders may bid more cautiously in earlier rounds and as a result not win their preferred combination of goods. This is explained in more detail in Section 5.1 below.

In the context of firm access rights, it may be useful to distinguish between existing capacity and new capacity. While it may be desirable to sell all existing capacity at once, it is less clear for how long existing (e.g. three years ahead under current practice) and new capacity should be allocated, and how often the prospect of new capacity should be brought to the market. It may also be desirable to allocate existing capacity and new capacity through a single auction.
Given the underlying uncertainty about future demand, it may not be efficient to allocate capacity too far ahead in the future. A possibility, which is raised in Section 5 below, is to allocate the rights to new capacity for the (regulatory) life of the assets.[6] This way, the capacity is fully allocated to those bidders who have paid for it. An efficient secondary market can then reallocate such capacity in the future if existing right holders are no longer the high value users.

In practice, however, it will be necessary to go back to the market regularly to allocate spare capacity, arising either as a result of rights that have expired or because not all existing capacity has been allocated in the auction. As suggested in the Discussion Paper, this could happen once a year. The worked example presented in Section 5 explores some of the practical issues that will arise in terms of auction scheduling.

Moreover, from a broader government perspective, there may be other reasons to avoid a big bang auction where as much new (and existing) capacity as possible is sold in a single auction too far in advance. For example, there is a great deal of uncertainty about the role that

[6] In practice, inter-regional access will be supported by an assortment of assets with different ages and lifespans. This means that if rights were to be issued for the duration of the life of the assets, instead of annually as in the discussion paper, an average life span will need to be calculated.

renewables will play in the provision of electricity, and the implications for the development of the network. In this environment it may be beneficial not to commit to build new capacity too far ahead in the future. Of course, long-term sales may help to fund long-life assets that are constructed now but will provide long-term capacity. Thus, the optimal policy will likely strike a compromise between the benefits of committing to building new capacity far ahead and the costs of doing so in light of uncertainty.

In summary, there is a range of potential practical frameworks that could be considered, including the annual allocation of existing spare capacity alongside the allocation of new capacity (if the auction reveals sufficient demand to support an expansion), and arrangements whereby firm rights for existing capacity are awarded for a particular year while rights for new capacity are awarded for the duration of the (regulatory) life of the new asset(s). These choices, however, interact with the auction format.

5. AUCTION FORMAT

The previous section discussed the preliminary issues that must be addressed in designing an auction, including defining the nature of the good that is to be allocated. In this section we discuss a range of issues, emphasising auction mechanisms that may be suitable for the allocation of firm transmission rights.

5.1 Simultaneous versus sequential auctions

Generally, and as a matter of economic theory, there are some benefits from selling similar goods sequentially. For example, if bidders want more than one good, then selling sequentially might give these bidders the opportunity to mitigate (but not eliminate) the exposure problem. A bidder for whom lots are substitutes or complements might be very cautious in submitting bids for multiple objects offered simultaneously, for fear of winning "too many" or the "wrong" combination of lots in a static auction. However, even selling sequentially, it is still the case that such bidders would bid more cautiously in earlier rounds and as a result not win their preferred combination of goods. As discussed in Section 5.2 below, a well-designed dynamic auction better addresses the exposure problem than selling objects sequentially.

The costs of selling sequentially, however, can be significant. Even when objects are identical (and buyers only want one object), there are several reasons why identical objects could fetch different prices in a sequential auction.[7] Identical objects or sufficiently similar objects fetching different prices at auction are problematic; in particular because of a perception that auction outcomes are not fair or equitable.[8] Another potential cost of sequential auctions is their impact on entry. To the extent that entrants, especially larger firms, might need to secure their preferred combination of lots to make their participation worthwhile, simultaneous auctions might be preferred to sequential auctions.

The issues associated with how much capacity to allocate at each particular auction and the frequency of such auctions were discussed under Section 4.2 above. While that discussion pointed out that the timing of taking existing or new capacity to the market is ultimately a policy decision, theory is much clearer about intra-allocation design – all rights to be allocated at a particular point in time should be sold in simultaneous rather than sequential auctions. To be

[7] See, for example, Menezes, F.M. and Monteiro, P.K. 2003, 'Synergies and Price Trends in Sequential Auctions', *Review of Economics Design* vol. 8, pp. 85-98 for a theoretical explanation and Jones, C., Menezes, F.M. and Vella, F. 2004, 'Auction Price Anomalies: Evidence from Wool Auctions in Australia', *Economic Record* vol. 80 no. 250, pp. 271-288 for empirical evidence.
[8] Milgrom, P.R. and Weber, R.J. 1982, "A Theory of Auctions and Competitive Bidding", *Econometrica,* vol. 50, pp. 1089-1122 report the failure of the RCA transponder auctions in 1981 to achieve similar prices for similar auctions as underlying a legal challenge by one of the bidders.

clear, a simultaneous allocation refers to selling all rights at the same time, possibly in an auction with a sequential or dynamic structure (see below). By simultaneous allocation we do not mean a one shot or static auction.

5.2 Static versus dynamic

In a static auction, bidders have no opportunity to update their bids in response to the bids of other participants. A common static auction format is a first-price sealed-bid auction, which can allow for combinatorial bids. Under this format, bidders submit a single bid for each object they want (or combinations of objects if they are allowed). The winner of an object is the bidder with the highest bid for the object and she pays her bid. If combinatorial bids are allowed then the winning allocation and price are determined in an appropriate manner (e.g. the highest total revenue over all possible combinations).

Static auctions can also be more sophisticated and allow for bidders to more fully express their preferences – so they can indicate how many MW of firm access they want at different prices but will have no opportunity to revisit their bids as a response to the bids of other participants. In what follows, we restrict our discussion to first-price sealed-bid auctions, which are the most commonly used static auction format. The analysis below, however, applies more broadly to static auctions including multiple-unit uniform price auctions of the type used in the National Electricity Market. Section 5.5 explicitly explains the shortcomings of using a static NEM-like auction to allocate firm access rights.

Dynamic auctions have some clear advantages over a static, single-round, sealed-bid auction. First, bidders have the opportunity to learn about how others value the objects as the auction progresses. This helps to mitigate the winner's curse[9] as bidders realise that their valuations are not too optimistic. Second, the information about relative prices for the various objects allows bidders to redefine their valuations over objects that are similar – so that they can substitute more expensive objects for less expensive objects – and over objects that are complementary – so that certain combinations of objects represent more value for money for the bidder than others.

[9] The winner's curse refers to a behavioural phenomenon in auctions, where a bidder's valuation depends on the information or values of other bidders (e.g. due to a common value) and the winner of the auction is the bidder with the most optimistic valuation, which by definition is greater than the expected value of the object for sale. Of course, rational bidders shade their bids to take into account of the winner's curse in auctions with common value components (e.g. bidders' information may be positively correlated). This has implications for the ranking of auctions according to expected revenue and efficiency. Roughly speaking, the linkage principle establishes that bidders shade their bids more the closer the auction price is to being determined by the information of a single bidder. For example, in a first-price sealed-bid auction, the auction price reflects only the information of the winning bidder.

There are also disadvantages vis-à-vis single-round sealed-bid auctions. Auctions where bidders can react to each other can give rise to perverse strategic behaviour. First, bidders can attempt to divide the objects amongst themselves through some form of signalling.[10] This would result in low prices and allocations that are not efficient as bids will not necessarily reflect bidders' valuations. It should be noted that there are several features of auction design, such as not revealing the identity of bidders during the auction, that can prevent or mitigate this behaviour.

Second, large bidders, who have market power, can affect prices in dynamic auctions. For example, large bidders can affect the final price by bidding for fewer lots than desired in a Simultaneous Multiple Round (SMR) auction as explained in Section 5.3 below. This can lead to smaller bidders choosing to bid only on the lots where prices are lower (as a result of the absence of the large bidder), softening competition for the other lots as well. This is the demand reduction phenomenon and can result in reduced overall competition, lower prices and inefficient outcomes, as prices will not necessarily reflect bidders' valuations.

In a single-round sealed-bid auction, such a strategy is unlikely to succeed as competitors will not learn about the demand reduction until the auction result is realised. However, even in a SMR auction, it is not clear whether bidders with market power will behave in such a way. Demand-reduction is costly; the bidder who pursues such a strategy ends up with fewer lots. A bidder who undertakes demand-reduction is generating a positive externality; they do not benefit in full from the demand reduction as some benefits accrue to their competitors. Each bidder might simply wait for other bidders to undertake the demand-reduction so that they can benefit from it at no cost. This creates a game similar to the prisoner's dilemma[11], where the predicted outcome is that no players undertake the demand reduction.

Bidders' market power in dynamic auctions is also associated with collusion. For example, suppose there are three lots for sale and three bidders in a SMR auction. Although each bidder might want up to two lots, it might be profitable for them to agree to bid only for one lot each. This way, each bidder receives a lot at the auction reserve price. The fact that bidders may be able to observe or infer whether or not their competitors are complying with the collusive

[10] For example, a bidder in a SMR auction might follow a 'tit-for-tat' strategy where they will bid only on selected items as long as their competitors do not bid on those items. Otherwise, they would bid aggressively on the items that are preferred by their competitors. See, for example, Menezes, F. M. 1996, "Multiple-Unit English Auctions", *European Journal of Political Economy*, vol. 12, no. 4, pp. 671–684 and Brusco, S. and Lopomo, G. 2002, "Collusion via signalling in simultaneous ascending bid auctions with heterogeneous objects, with and without complementarities", *Review of Economic Studies*, *69*, 407-436.

[11] The prisoner's dilemma is a type of game in which two players may each "cooperate" with or "defect" (i.e. betray) the other player. In this game, as in all game theory, the only concern of each individual player ("prisoner") is maximizing his/her own payoff, without any concern for the other player's payoff. The unique equilibrium for this game is the inefficient outcome where both players *defect* even though each player's individual reward would be greater if they both played *cooperate*.

agreement in a SMR (e.g. if they can observe bids or if the number of bidders is very small) but not in a sealed-bid auction makes the former more vulnerable to collusion than the latter.

Third, dynamic auctions may also have a detrimental effect on entry. For example, consider a weak bidder who knows for sure that they can be outbid by a strong bidder in a dynamic auction. If participation is costly the weak bidder might simply not participate. As a result, competition is reduced and the strong bidder might win the object at the reserve price or at a very low price if there is no reserve. In contrast, in a sealed-bid auction the strong bidder has an incentive to place a low bid to win the object and secure a high profit margin and therefore the weak bidder stands a chance of winning the object and may still participate.

Fourth, a dynamic auction might in principle be strategically simpler than a sealed-bid auction – a bidder has only one chance to get it right in the latter auction and, therefore, needs to consider upfront all strategic implications of his bid and all possible bids by their competitors. In the former auction a bidder can fully develop his strategy after observing at least part of his competitors' strategies, which reduces the number of computations required. However, dynamic auctions typically require specific rules to ensure that information is revealed over time. These rules increase the auction complexity and may affect bidders' incentives for and ability to fully express their preferences for objects.

Finally, both static and dynamic auctions are subject to the exposure problem. As discussed above, the exposure problem arises when bidders view different objects as substitutes or complements. A bidder may be afraid to bid aggressively on a set of objects, since if they win some and loses others they may end up paying more than their valuation. Cautious bidding – when one bids considerably below their valuation – can result in lower revenue for the seller. It can also result in efficiency losses as we can no longer guarantee that the bidders with the highest valuations will be allocated the relevant lot. However, the impact of the exposure problem, and possible solutions, differs significantly across static and dynamic auctions and its extent depends on the nature of bidders' valuations as discussed in Section 3.2 above. To be clear, we are referring to whether potential bidders consider access at different DICs to be substitutes or complements. The expectation is that bidders' heterogeneity means that the structure of the valuation will vary across the different classes of bidders (e.g. generators, retailers, investors).

In the presence of complementarities between objects, the nature of the strategic uncertainty faced by bidders in a sealed-bid auction implies that auctions outcomes are unlikely to be efficient. In contrast, while dynamic auctions are also subject to the exposure problem as bidders do not know how their competitors will bid in subsequent rounds for the various components of their favourite combinations, there are possible fixes. For example, as explained in Section 5.3 below, to overcome the exposure problem, the US Federal Communications Commission (FCC) SMR auction format allows bidders to withdraw high bids (subject to penalties). This allowed bidders to back out of failed attempts at aggregation of objects. However, available evidence suggests that bid withdrawals were not used with this objective, but rather were used by bidders as a signalling device to try to sustain tacit collusion.[12]

A second approach to overcome the exposure problem in SMR auctions of complementary objects is to allow bidding for combinations. We do not examine SMR with combinatorial bids in this paper but note that the existing empirical and experimental evidence suggests that SMR auctions without combinatorial bidding can perform well – that is, yield efficient allocations and substantial revenue – when complementarities between objects are mild.[13] A final approach to mitigate the exposure problem is to use a clock auction. Below we describe in detail both SMR and clock auctions. The analysis below includes an explanation of how each auction works, an outline of its strengths and weaknesses, and a short review of empirical/experimental evidence relating to each of the auction designs when such evidence is available. We also include a worked example of how a clock (ascending price) auction might work and highlight the associated auction design choices that the auction would entail. The analysis is necessarily high level for the reasons outlined in the introduction.

5.3 Simultaneous multiple round (SMR) auctions

Since its introduction by the FCC in 1994, this auction has become the standard format for auctioning spectrum across the globe. The FCC, for example, has used this format over 70 times. In Australia the Australian Communications and Media Authority (and its predecessor) has also used SMR auctions since the late 1990s. The basic auction format and associated rules are described below, as well as its weaknesses and strengths. Although SMR auctions have performed well in the allocation of radiofrequency spectrum – and they have been modified over time to mitigate some of their potential flaws – the increasing need to ensure that bidders are able to assemble an appropriate "package" of spectrum (both in terms of location and bandwidth) has led to the proposal of a more substantive change in SMR auctions to allow for package bidding.

[12] See Cramton, P., Shoham, Y. & Steinberg, R. 2004, *Combinatorial Auctions*, University of Maryland, p. 15.
[13] See Goeree, J., Holt, C. & Ledyard, J. 2007, ""An Experimental Comparison of the FCCs Combinatorial and Non-Combinatorial Simultaneous Multiple Round Auctions" (with C. Holt and J. Ledyard)"", *Report to FCC* and Cramton, P. 1997, "The FCC spectrum auctions: An early assessment", *Journal of economic management and strategy,* vol. 6, no. 3, pp. 431-495.

5.3.1. How does it work? Its weaknesses and strengths

A SMR auction works as follows: Individual lots are sold simultaneously. In the context at hand, a lot would consist of a strip (say 10 or 20 MW) for each DIC in a particular direction, and it may be possible to distinguish between lots associated with existing capacity and lots associated with new capacity.[14] To illustrate, suppose that both existing and new capacity will be sold in a single SMR auction and there are only two DICs in the network, each with 100 MW capacity. Suppose that new capacity is optimally built in blocks of 100 MW. In this simple example, each lot could consist of 20 MW so there would be 5 lots of existing capacity for each DIC, 5 lots of the first expansion of 100 MW for each DIC, etc. In what follows, I describe how SMR auctions work in general and later comment on some challenges in designing an SMR auction in the context of firm access rights.

The auction proceeds through multiple, discrete rounds. In each round, eligible bidders may submit valid price bids for any lot. A valid bid is one that exceeds the standing high bid for that lot by a specified minimum increment. At the end of each round, the highest bid for each lot becomes the standing high bid for that lot. If no new bids are received, the previous standing high bid remains the standing high bid.

A bidder is eligible to bid for any number of lots if her eligibility level[15] is greater than or equal to (i) the activity weight of the lots for which she is currently the high bidder plus (ii) the activity weight of the new lots in the list of lots she is bidding on in the current round. The activity weight of a lot is predetermined by the auction mechanism and is typically a function of the lot characteristics. A bidder maintains activity levels from round to round by submitting valid bids or remaining the high bidder on a sufficient number of lots.

Activity rules usually become tighter as the auction progresses. For example, in the first few rounds a bidder might maintain eligibility by submitting valid bids on 85% of the nominated number of lots, while this percentage might increase to 100% in later rounds. The auction ends when no valid bids are received on any lot. Winning bidders pay their bids. Note that while SMR auctions are not uniform price auctions, the design itself, by allowing bidders to switch between lots as they become more or less expensive, should result in similar prices for similar lots. For

[14] It is not unusual for SMR auctions to allocate a large number of lots (e.g. over 200) but complexity (both computational and strategic) is likely to increase substantially as the number of lots increases.

[15] Each bidder starts with some eligibility (number of lots she is allowed to bid for) usually determined by the bidder herself and backed by a deposit or a bond. Activity in a round consists of new bids and standing high bids from the prior round. A bidder's eligibility is typically influenced by her bidding behaviour. For example, to retain eligibility for n lots, the bidder may be required to have bid or have the highest standing bid in a fraction, say 80 per cent, of n. It is common to have that fraction converge to 100 per cent as the auction progresses. See, for example, http://web.stanford.edu/~jdlevin/Econ%20285/SAA%20and%20Spectrum%20Sales.pdf.

example, in a SMR auction, it is expected that prices for lots associated with existing capacity at a particular DIC should fetch similar if not identical prices.

There are also other rules such as withdrawal penalties[16] that are associated with this auction design.

A main advantage of a SMR auction from the viewpoint of bidders is that it provides a simple price discovery process. The rules are simple and when the lots being sold are substitutes it allows bidders to switch from bidding for one lot to bidding for another lot to take advantage of price differentials. If there are many opportunities for substitution of lots in a way that allows bidders to piece together desirable packages then this format can lead to the efficient realisation of synergies or economies of scope by bidders.[17] As SMR auctions are dynamic in nature, they help reduce the winner's curse by revealing common value information during the auction. To the extent that there is uncertainty about the market valuation of firm access, the dynamic nature of the SMR auction allows bidders to revise their valuations as they learn about how other bidders (in particular provisional winners) bid in the auction. The reduction in the winner's curse benefits bidders who are more confident about their own valuations when bidding, but also usually results in efficient outcomes.

SMR auctions also have several potential weaknesses from the point of view of bidders. First, the pricing rule can provide incentives for large bidders to follow a "demand reduction" strategy. The following simple example illustrates how demand reduction works. Consider two bidders 1 and 2 and two objects A and B. Bidders want both objects. A possible history of bids where each bidder bids for the two objects in round 1 and for only one object in round 2 is as follows:

Possible history of bids for objects A and B, respectively:

	Bidder 1	Bidder 2
Round 1	(5,6)	(6,5)
Round 2	(7,6)	(6,7)

Under this bidding history, and assuming that no bidder is willing to increase her bid, the auction ends after the second round at prices (7, 7) with Bidder 1 winning object A and Bidder 2 winning

[16] Typically the highest standing bidders can withdraw their bids subject to a bid withdrawal penalty. If a bidder withdraws its high bid, the seller will be listed as the high bidder and the minimum bid is the second-highest bid for that item. The second-highest bidder cannot be responsible for the bid, since she may have moved on to other items. If there are no further bids on the item, the auctioneer can reduce the minimum bid. To discourage gaming, a withdrawal penalty is set as the larger of 0 and the difference between the withdrawn bid and the final sale price. See, for example, http://www.cramton.umd.edu/papers2000-2004/cramton-simultaneous-ascending-auction.pdf.

[17] For an early evaluation of the use of SMR auctions in the allocation of PCS licenses in the US, see Ausubel, L., Cramton, P., McAfee, R. and McMillan, J. 1997 "Synergies in Wireless Telephony: Evidence from the Broadband PCS Auctions," *Journal of Economics and Management Strategy* vol. 6, pp. 497-527.

object B. If instead both bidders reduce their demands in the first round and bid only for one object each, say Bidder 1 bids 5 for object A and Bidder 2 bids 5 for object B, then the auction ends after the first round at substantially lower prices (5, 5).

Although demand reduction might be seen as providing an advantage for large bidders, as by design a SMR auction confers them market power[18], it substantially complicates the strategic problem faced by all bidders (large and small).

Second, SMR auctions are subject to the possibility of tacit collusion; bidders might use their bids to signal their intentions to other bidders and in doing so they might secure an allocation of lots at low prices. An example of such signalling strategies occurred during the earlier FCC auctions when bidders used the trailing digits of their bids to signal other bidders and support tacit collusion. The FCC subsequently changed the auction design by limiting bids to integer multiples of the minimum bid increment.[19]

Third, activity rules, while important to ensure that bidders do not hide their total demands and impede price discovery, can lead to strategic behaviour where bidders maintain eligibility by bidding for lots that are not of interest and later transfer their eligibility to the lots where their true interest lies. Fourth, as discussed above, bidders are subject to the exposure problem: when bidding on individual lots, there is the possibility that a bidder will secure only some of the lots that it needs, undermining the value of its winnings.

Note that while some of these weaknesses might be seen as creating a possible advantage for some bidders, and in particular large bidders (e.g. the possibility of signalling through bidding behaviour or the ability to park eligibility on unwanted lots to fool their rivals), they substantially complicate bidding strategies and might result in high valuation bidders missing out on winning their desired lots.

The appendix covers a recent experience with SMR auctions in the US for the sale of advanced wireless services (AWS). This recent experience highlights that while SMR auctions have performed well in simple situations with a single geographic scheme, they can lead to potentially inefficient allocation in complex settings.

[18] There are of course many reasons why a large bidder might not be willing to explore its market power. For example, by reducing its demand, a large bidder can decrease the price it pays but by doing so will benefit its competitors and incur a cost (the number of lots that the large bidder has to give up in order to affect the price). This creates a free-rider problem as a large bidder that reduces its demand incurs all the costs associated with such a strategy but shares the benefits - i.e. the lower price – with other bidders.

[19] See, for example, Crampton, P. & Schwartz, 2002, "Collusive bidding in the FCC spectrum auctions", *The B.E. Journal of Economic Analysis and Policy*, vol. 1, issue 1, available at www.bepress.com/bejeap/contributions/vol1/iss1/art11.

We now return to the potential applicability of SMR auctions for the allocation of firm access. As the description above suggests, SMR auctions were designed primarily to allocate existing supply of a particular object such as spectrum of frequency for mobile telephony or licences to extract timber from existing tracts. In such cases, bidders' preferences are such that the objects are substitutes or complements but supply is fixed.

Whereas firm access rights at different DICs may be substitutes or complements, from the viewpoint of bidders, it does not matter whether firm access at a DIC is met by existing or new capacity. However, the auctions are meant to ensure that new capacity is built in an efficient manner – when the value that bidders assign to access to new capacity exceeds the cost of expansion. This complicates matters as foreshadowed above. For example, it may be necessary to design the auction in a way that the initial round only allows for bids for existing capacity[20] and the first tranche of new capacity for each DIC. If there are enough bids to justify the first tranche, then bidders may be allowed to bid for a further expansion in a second round. We are unaware of an SMR auction with these characteristics so additional work needs to be done to flesh out how a SMR auction may work in practice in the case of firm access and to compare it with alternative formats in terms of efficiency.

5.4 Clock auctions

The limitations of SMR auctions that have been pointed out above have led to the development of alternative auction formats known as clock auctions. For example, ACMA used a simplified version of a combinatorial clock auction in the recent allocation of 4G spectrum.

A clock auction is an auction where all perfectly substitutable (homogeneous) items are bundled together and share the same "clock". In the case at hand, a "clock" may be set for each DIC and the object for sale defined as an annual 1 MW strip. Below we further develop how a clock auction may work in this context.

For each "clock", the auction system sets a price which increases as long as demand exceeds available supply at that price. The auction ends when demand equals supply and each bidder

[20] Recall that for illustration purposes we are assuming that existing and new capacity is sold in one auction. While we understand that existing capacity is already sold at auction (for up to three years ahead), it may be desirable to sell them in a single auction.

receives the quantity they bid for at the market clearing price. The simultaneous closing of all clocks allows bidders to secure their optimal combination of lots.[21]

There are some key differences with SMR auctions. First, whereas bidders bid prices in SMR auctions, they bid quantities in clock auctions. Second, by design, every successful bidder in a particular clock pays the same price. While we expect a well-designed SMR auction to set similar prices for similar lots, this is not guaranteed as it depends on bidding behaviour conforming to the incentives set by the design.

A useful way to illustrate the difficulty in making a final recommendation for an auction design without fully anchoring some of the key design parameters is to consider an example of how a clock auction would work in the context of allocating firm access rights. To be clear, the worked example below is meant to illustrate the choices that will have to be made and how these choices interact with the design of the auction. It is not an endorsement or final recommendation for the choice of a clock auction.

5.4.1. A worked example

The starting point is the product definition. For illustration purposes, existing spare capacity and new capacity is to be sold at the auction. Existing spare capacity is sold as annual 1 MW strips for a particular DIC. New capacity, on the other hand, is sold as 1 MW strips for the duration of the average lives of the new assets, assumed to be 20 years in this example. This is explained further below.

As indicated, this example is meant to illustrate how product definition and auction design interact and to suggest how an auction of firm capacity might work and not how it should work. Arriving at a workable design will require substantive additional research. The next section describes some of the key steps involved in designing and implementing an auction.

In this example, there is one clock for each DIC but we focus here on the case of a single DIC. In practice, rules will need to be established governing how bidders switch across different clocks. Also, here we ignore the fact that electricity can flow in two directions and consider instead a one-direction problem.

[21] Ausubel, L.M. 2006, "An Efficient Dynamic Auction for Heterogeneous Commodities", American Economic Review, vol. 96, no. 3, pp. 602 introduced a final proxy round in which bidders express values for any desired packages of blocks. An efficient assignment of blocks is found using a maximisation algorithm based on the proxy bids and the bids in the clock phase.

The second step is for the auctioneer to announce a reserve price and the LRIC (or a similar concept such as Deep Connection Charges (DCC)) so bidders know when an expansion will be triggered. As illustrated below, at each round bidders bid the quantity of access they wish to buy at the announced price for each period from year 1 to year 20.

The allocation rule is such that existing capacity is allocated for the years in which demand (as expressed by bids) is less than existing capacity. When an expansion is triggered, by demand being greater than existing capacity and the price being sufficiently high, the new capacity is then allocated for a period of 20 years. Note that these parameters are “moving parts” and in practice will be determined in consultation with stakeholders. This implies that, necessarily, any auction design can only be firmed up when the discussions about these broad parameters are settled. Even after these parameters are chosen, the auction design may still change as a result of any flaws or issues that may become apparent through laboratory testing.

To be more specific, consider the following parameters. There are three bidders who value firm access. These bidders could be generators, retailers or investors. Without getting into details of which concept of cost to use, we simply note that existing capacity is equal to 100 MW and that 100 MW expansions are triggered at prices equal to $20 and $50. That is, the total cost of the first 100 MW expansion is $2000 and the total cost of the second (a further 100 MW) is $5000. These values may have been derived either from the DCC estimates or from summing up the LRIC up to the expansion points.

As indicated above, for practical purposes we assume an asset life of 20 years (to coincide with regulatory practice). That is, in this example, the product associated with new capacity is a strip (1 MW) for 20 years. This annual strip is fully tradable.

The auction starts with the auctioneer announcing a reserve price, which we set to zero in this example to reflect the average cost of existing capacity, and requesting quantity bids (MWs). Thus, in the first round, we have the following hypothetical bids (which are not assumed to be equal to valuations):

Table 1 Round 1 bids (Reserve price = 0)[22].

	Year 1	Year 2	Year 3	Year 4	Year 5	……	Year 18	Year 19	Year 20
Bidder 1	30	35	40	40	--	--	--	--	--
Bidder 2	20	25	35	35	--	--	--	--	--
Bidder 3	30	35	50	50	--	--	--	--	--
Totals	80	95	125	125	--	--	--	--	--

Note that the demand (as expressed by these bids) falls short of supply for years 1 and 2, so each bidder receives an allocation equal to their bids for these two years at a price equal to zero. Therefore, there are 20 MW of existing capacity not allocated for year 1 and 5 MW for year 2. We will return to what happens to these unallocated amounts post-auction.

However, for year 3, demand exceeds supply. Under the proposed auction format, bidders are not allocated any access for years 3 to 20 in this case and the auction continues to set prices for access from year 3 onwards. The second round starts with the auctioneer announcing a higher reserve (e.g. along the LRIC curve). For example, the auctioneer announces a reserve price equal to $15 and bids are as follows:

Table 2 Round 2 bids (Reserve price = 15).

	Year 3	Year 4	Year 5	……	Year 18	Year 19	Year 20
Bidder 1	35	39	--	--	--	--	--
Bidder 2	30	34	--	--	--	--	--
Bidder 3	45	45	--	--	--	--	--
Totals	110	118	--	--	--	--	--

Note that the demand for year 3 exceeds supply so this round ends with no further allocation and a new round will follow with a higher reserve. Suppose that the reserve price for round 3 is set at $20, which will trigger an expansion, and bids are given by:

Table 3 Round 3 bids (Reserve price = 20).

	Year 3	Year 4	Year 5	……	Year 18	Year 19	Year 20
Bidder 1	32	38	--	--	--	--	--
Bidder 2	28	33	--	--	--	--	--
Bidder 3	40	44	--	--	--	--	--
Totals	100	115	--	--	--	--	--

Now demand for access in Year 3 is exactly equal to supply so an allocation can be made for Years 3 to 23 (recall asset life = 20 years) equal to the year 3 bids and an expansion will be triggered adding 100 MW additional capacity to be allocated from year 4 onwards.

[22] Firms may have placed bids for years 5 to 20 that are not shown here as they are not important in this instance.

Before we continue, at the end of Round 3 these are the allocations of existing capacity made at the various prices. The cleared volumes are duplicated from years 4 to 23 as the existing capacity is now fully allocated for the next twenty years.[23] Note that the new capacity is built from year 3 onwards (we assume that capacity is built instantaneously) but it has not yet been allocated.

Table 4 Allocations made by the end of Round 3 and prices – auction will still continue as Year 4 has not been cleared.

	Year 1	Year 2	Year 3	Year 4	Year 5	……	Year 21	Year 22	Year 23
	At price =0		At price = $20 (paid only once)						
Bidder 1	30	35	32	32	32	32	32	32	32
Bidder 2	20	25	28	28	28	28	28	28	28
Bidder 3	30	35	40	40	40	40	40	40	40
Totals	80	95	100	100	100	100	100	100	100

To be clear by the end of Round 3, here are the temporary payments to be made by the successful bidders:

Table 5 Committed Payments at the Allocations made by the end of Round 3.

	Years 1-2	Years 3-23
Bidder 1	0	640
Bidder 2	0	560
Bidder 3	0	800
Totals	0	2000

The auction has not finished yet as there is now 100 MW of excess capacity to allocate from years 4 onwards so bids for the new capacity are then requested. Assume that the reserve price is set equal to $25 (e.g., again along the LRIC curve). Suppose the bid profiles are as follows:

Table 6 Round 4 bids (Reserve price = 25, new capacity).

	Year 4	Year 5	Year 6	……	Year 22	Year 23	Year 24
Bidder 1	15	15	--	--	--	--	--
Bidder 2	20	20	--	--	--	--	--
Bidder 3	25	25	--	--	--	--	--
Totals	60	60	--	--	--	--	--

[23] To be clear, in this example existing capacity is sold in 1 MW strips annually only until there is an expansion, after which the capacity is allocated for 20 years. However, buyers should be able to trade their annual allocations in the secondary market or in the auction market as existing capacity.

As the sum of the quantity bids is less than the new supply (100 MW), all bids are successful at a price = 25 and the following allocations are made (in addition to those made in Round 3) and the auction ends as there is no excess demand for years 5 onwards:

Table 7 Allocations made by the end of Round 4 of the new capacity at a price = 25.

	Year 4	Year 5	Year 6	……	Year 22	Year 23	Year 24
Bidder 1	15	15	15	15	15	15	15
Bidder 2	20	20	20	20	20	20	20
Bidder 3	25	25	25	25	25	25	25
Totals	60	60	60	60	60	60	60

The new payments to which the bidders have committed at the end of Round 4 are as follows:

Table 8 Committed Additional Payments at the Allocations made by the end of Round 4.

	Years 4-24
Bidder 1	375
Bidder 2	500
Bidder 3	625
Totals	1500

The final allocation of firm access rights can be obtained by adding up the amounts in Tables 4 and 7 and the total payments committed by bidders can be obtained by adding up the amounts in Tables 5 and 8. Note that all successful bidders pay the same price for capacity, but the price of existing capacity is different from that of new capacity.

As indicated above, this example is for illustration purpose only. It is meant to illustrate choices that are part of the auction design. For example, if only new capacity is allocated in the auction, as per the AEMC staff Discussion paper (December 2014), a minimum bid volume and price (and hence auction revenue) is locked in at each round, and as such one can determine what size capacity expansion (if any) can be supported by the auction revenue.

Along with product definition and how long to allocate existing and new capacity for, the following decisions will also impact upon the choice of the auction format:

1. When will payments be due? Payments associated with existing capacity can be seen as congestion charges and could be payable at the end of the auction. However, it may be that payments associated with new capacity to be added two or three years from the completion of the auction should be deferred, which adds another layer of complexity needed to deal with the possibility of future default. While this may be dealt with separately,

the payment arrangements can influence the incentives faced when bidding in the auction and, therefore, need to be taken into account during the auction design.

2. How should the auction revenue be treated? If there are congestion rents (associated with the allocation of existing capacity), then they could be subtracted from the regulated firm's maximum allowable revenue. However, this means that all users (not only those who were successful in the auction) would benefit, potentially creating an incentive to underbid in the auction (this needs to be carefully analysed). Revenue associated with the expansion of capacity would be offset against the cost of expanding capacity in a neutral way. The take away point again is that the treatment of auction revenue can influence bidding behaviour in adverse ways and needs to be considered as part of the auction design.
3. What happens post-auction to unallocated capacity? For the worked example, during year 1, one can sell the existing spare capacity for year 2 (only 5 MW), year 3 (100 MW), etc. The auction periodicity and the contract term will need to be designed so that they match each other. While unallocated capacity would be sold in a short-term auction (up to three years out) under the current OFA design, the worked example above suggests that other arrangements are possible and ought to be explored, to the extent they have not already been. This also includes consideration of alternative shapes for the issued firm access in later periods to avoid having large unallocated capacity in later years.

A further complication arising from the example above is related to how to handle the fact that electricity can flow into two directions, giving rise to common costs that have to be allocated. It is possible that the auction format above can be changed to accommodate the two directions by recalculating reserve prices so that when the demand from both sides reaches existing capacity, an expansion is triggered. In the example above, the reserve price for the first tranche of new capacity would be set equal to $10 and for the second tranche the price would be set at $25. The first expansion is triggered when the demand from one side exceeds (or is equal to) 100 MW **and** the total demand from both sides exceeds (or is equal to) 200 MW. There remains an issue of how to allocate the common costs, which may depend on MW in each direction.

It is unclear from the AEMC staff Discussion Paper (December 2014) whether these common costs are material. If they are not, then perhaps they can be built into the LRIC (i.e. the reserve price) based on some rules of thumb. This can be updated regularly based on actual flows but of course there are no guarantees that one direction will not subsidise the other direction.

Even if these costs are material, the clock auction should be able to take them into account. For example, since a minimum level of auction revenue is guaranteed after each round (bids times price), it will be seen if there is sufficient auction revenue from a DIC pair to cover the cost of an expansion (including the common costs). The capacity expansion will then consist of some amount of expansion in each DIC direction. The incentives that bidders face under such arrangements will need to be fully explored by additional analysis, including laboratory testing.

5.5 Why a NEM-style auction may not be appropriate

Given the familiarity of potential bidders for firm access rights with the NEM auction, it is worth considering whether a similar design may not be appropriate. To recall, in the NEM bidders (generators) submit a supply schedule (the quantity they are willing to supply at the various prices in the price grid) for each 30 minute period over the next 24 hours. It is a uniform price auction where every successful bidder receives the market clearing price, determined by the intersection of the horizontal sum of the supply schedules submitted by generators and the system demand.

Bidders are allowed to rebid prior to the auction clearing but the rebidding simply reflects changes in information (e.g. about demand) and other considerations that are internal to the firm. As rebidding is not a response to the bids of other generators, this is essentially a static format.

There are, however, two key distinctions between the NEM auction of wholesale electricity and the sale of firm access rights. First, while the NEM auction is static in nature, essentially the same bidders submit 48 bids (and rebids) each day. This means that there is an opportunity for bidders to learn about their competitors' costs from observing the outcomes across auctions (despite the lack of feedback during an auction). In contrast, firm access rights are unlikely to be sold more frequently than annually. Second, the structure of the values of bidders for access rights is likely to be more complex than those of bidders in the NEM. This is because potential bidders for firm access rights include generators but also retailers and investors who may wish to buy access rights at different DICs. As discussed above, static auctions do very poorly in such an environment.

In summary, sealed-bid auctions are easy to run, low-cost and robust, and are familiar to those who bid in the NEM. However, the inefficiencies associated with the exposure risk explained above become more significant as the complexity of the allocation problem increases. At some stage, the net benefits of a more sophisticated auction format such as a clock auction or an SMR auction will dominate the economic, political and administrative net benefits associated with a simple auction format.

The suitability of a NEM-style, static, sealed-bid auction where bidders submit a demand schedule specifying the quantity of MW of firm access they are willing to buy at each interconnector, will depend upon the nature of bidders' values and the complexity of the problem that they face.

5.6 Existing experimental evidence comparing different auction formats

There are several experimental studies that examine the performance of particular auction formats. An auction experimental study tries to replicate the main features of an auction in the context of a laboratory and provide subjects with the incentives to behave in a profit-maximising way.[24] Brunner et al. (2010)[25] compare four different auction formats in a controlled lab experiment. They compare the standard SMR auction with the SMR auction with package bidding and two other combinatorial clock auction formats. In their experimental design they consider a situation with eight bidders, 12 lots and various degrees of complementarity between lots. They consider two types of bidders in their design: six small bidders and two large bidders.

The results are revealing. First, with high complementarities, the combinatorial auction formats (including SMR with package bids) do better than the SMR auction in terms of efficiency (allocating the licences to those bidders who value them the most). However, with low complementarities, the SMR auction performs quite well in terms of efficiency. The poor performance of the SMR auction in terms of efficiency when complementarities are high is mainly due to the exposure risk explained above. This experimental evidence can be seen as providing support for selecting a clock auction for the allocation of firm access rights if bidders' valuations exhibit complementarity. Even in the absence of complementarities, clock auctions perform well. This experimental evidence also provides support for a SMR auction to allocate firm access if some of the complexities raised in Section 5.3 above can be overcome and if access rights at various DICs are seen by (at least some) bidders as substitutes or exhibit low complementarities.

5.7 Reserve prices

Reserve prices typically play two distinct roles in auction design. Their most important role is to ensure that, in the absence of competition or in the presence of collusion the seller only sells at

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[24] For an introduction to the use of experiments in economics see, for example, Smith, V. 2008. "Experimental methods in economics", *The New Palgrave Dictionary of Economics*, 2nd Edition. An earlier version is available at http://www.leex.upf.edu/leex/files/Inaugural_Lecture_at_the_%20LeeX_by_Vernon_L._Smith.pdf.
[25] Brunner, C., Goeree, J.K, Holt, C.A. & Ledyard, J.O. 2010, "An Experimental Test of Flexible Combinatorial Spectrum Auction Formats." American Economic Journal: Microeconomics vol. 2(1), pages 39-57.

a price above her reservation value - the value the seller places on keeping the object for her own use or to resell later. The second role of reserve prices in auctions is to potentially increase the seller's revenue by setting a reserve price above the seller's value. Ultimately, the net impact on revenue will depend on a number of factors including the trade-off between more aggressive bidding and the lower number of actual bidders resulting from setting a high reserve, and the risk that no potential buyers would be willing to bid above the high reserve.

In the case of auctioning firm access rights the focus is solely on efficiency and, therefore, a reserve price set at the LRIC, for example, ensures that access is allocated to those who value it more than its cost. To the extent, however, that the LRIC is an (uncertain) estimate of the true long run incremental cost (the unitised value of capacity), some informed judgment will be required. For example, it is desirable to consider the impact of setting a reserve that is too high (allocated capacity is less than the efficient level) versus a price that is too low (allocated capacity is greater than the efficient level).

6. FROM CONCEPT TO IMPLEMENTATION: PRACTICAL STEPS IN ACTION DESIGN

There are a number of steps that are usually followed in the design of an auction. The first step is to define what is to be sold in consultation with stakeholders and to set some general parameters. This includes, for example, the allocation of existing capacity on an annual basis and the allocation of new capacity for a longer multi-annual period. This step also includes the determination of a methodology for the calculation of the Long Run Incremental Cost (or other relevant costs) to be used to set up the reserve price and the prices (and quantities) at which expansions will be triggered.

The second stage consists of procuring auction design expertise. At this stage the auction design, including the auction format but also the various micro rules (payment rules, treatment of default, activity rules, etc.), will be finalised. It is worth noting that modern auction designs are complex, especially where multiple items are being allocated and when this occurs within a dynamic environment with auctions spaced out over time.

For such designs, there are inevitably specific issues where theory does not provide clear guidance. It may be the case, for example, that there are arguments both for and against a particular design decision (for example, how much information should be released to bidders), and it is not clear how strong these arguments may be in a specific design context. It may also be the case that because of the complexity of the underlying problem the relevant theory is not yet worked out in the literature or well understood.

In this instance, carefully designed specific experiments are used to throw light on particular questions; it may not be necessary to put the whole design into the laboratory. In the laboratory, experimental subjects, working at computers in isolated booths, receive instructions, process information, make decisions, interact with other bidders, make bids, and have access to information that reflects the design being tested. They earn real money, and the stakes are sufficiently high that they have an incentive to earn the highest profits that they can. One can explore, for example, whether one design leads reliably to a more efficient allocation. One can also explore whether the auction converges to an equilibrium in reasonable time (some SMR designs used in the early spectrum auctions took weeks to converge), and whether the design is susceptible to tacit collusion. The implication is that adequate provision for experimental testing should be planned into the design process of a fit-for-purpose auction. This means in the first place, that adequate resources should be allocated to the experimental program. Secondly, and perhaps more importantly, enough time must be allocated to allow for both theoretical and experimental work, and for the interaction between them.

More complex auctions will need to be hosted electronically, which requires the development of a fit-for-purpose software platform. For example: clock auctions require separate time clocks for different DICs; clocks need to be reset within the auction to reflect activity rules (see footnote 15 for a description of how these work); bidders need to be able to switch bidding between DICs at low cost; and the auction needs to be drawn to a close according to specific rules. Similarly, SMR auctions require a large number of calculations to be completed between rounds of bidding to determine provisional winners (standing bids). Given this complexity, any implementation timeline needs to make adequate provision for specifying software requirements (including availability, security and redundancy standards), coding and testing; all after the auction design is largely settled. Other practical considerations include the development of auction processes such as registration, prequalification, probity and settlement.

The final step involves training bidders so that they become familiar with: how different functions of the auction are displayed; how to enter bids and other information; how to correct data entry mistakes; bidding rules (e.g. activity rules); how to conduct searches (where available); how to ask for assistance; security and probity protocols; etc. Similarly, auction administrators gain valuable experience in managing auction day by participating in these sessions. These sessions also reveal a range of practical issues that arise from the way bidders interact with screens, interpret instructions, respond to prompts, etc. Auction system designers will often modify instructions to remove ambiguity as a result of these sessions. Auction developers also conduct a full "dress rehearsal" of the auction event including management of emergency situations that could arise from system failures.

7. SUMMARY AND RECOMMENDATIONS

As mentioned in the introduction, the selection of an appropriate allocation mechanism is closely linked to defining what is being sold. This is because the most appropriate auction mechanism is closely linked to the choice of product definition. Despite this, we can draw some conclusions.

First, a NEM-style auction is likely to be an inferior allocation mechanism for firm access rights. There are two reasons for this. In the context where valuations have a common component (the resale value of the right) static auctions do not allow bidders to learn about the value of this common component. Moreover, when bidders want access at more than one DIC, they face an exposure problem in a NEM-style auction. Second, while a dynamic auction (such as a clock auction) may be preferable, the exact format that this will take needs to be developed further.

Nonetheless, the summary table below presents some of the possible alternative product definitions in the first column and the associated most appropriate allocation mechanism in the second column. A third column explains how the format is the best fit with the objectives and briefly discusses the relevant trade-offs. This is done for illustrative purposes only. We recommend that AEMC settles broad criteria with respect to product definition issues as a priority and then immediately engages a mechanism design specialist to specify the auction in detail. Even with the detailed designs here, there is substantial scope for custom rules and processes to address context specific issues.

Product Definition	Possible Auction Format	Rationale
Smallest possible unit (e.g., annual 1 MW at a particular interconnector)	Clock auctions with each interconnection with its own clock.	This type of auction facilitates the aggregation of bidders' preferred combination of rights across different interconnectors.
Smallest possible unit (e.g., annual 1 MW a particular interconnector)	NEM-style auction with bidders submitting a demand schedule for each interconnector they are interested in securing access at.	Bidders in the NEM are familiar with this format. If the impact of a common value and bidder heterogeneity is not material, it may lead to an efficient allocation under a uniform-price rule. It may be possible to investigate alternative (static) auction mechanisms where bidders are able to express their preferences more fully.
Bigger lots (e.g., annual 20 MW at a particular interconnector)	SMR auctions which are simple to run and have been used extensively. Further investigation is needed to determine whether the complications raised in Section 5.3 can be overcome.	In the absence of strong complementarities, SMR auctions can lead to an efficient allocation.

8. APPENDIX

Recent experiences with SMR auctions: The US AWS auctions[26]

The difficulties that SMR auctions face in allowing bidders to arbitrage between lots can be illustrated in a recent auction run by the FCC. This difficulty can potentially lead to low prices (due to limited substitutability between lots) but also no guarantee that bidders will be allowed to piece together their preferred combinations of lots.

The Advanced Wireless Services (AWS) auction sold 90 MHz of spectrum in 161 rounds and raised 14 billion dollars. The FCC specified a band plan determining the composition of each lot within the available bandwidth in each location. Each lot is a particular frequency band covering a given geographic area. Six frequency blocks of paired spectrum (A-F) were to be auctioned. Three blocks were 20 MHz and three were 10 MHz. The FCC divided the blocks in three different ways: for blocks D-F the country was split into 12 large regions; for blocks B and C the country was split into 176 medium-size regions; and for block A the country was split into 734 small regions.

Figure 1 shows the price per 10 MHz of spectrum for each of the blocks at the end of selected days in the auction. There are six bars (corresponding to blocks A through F) at the end of each day. A possible analogy to the allocation of firm access rights is that blocks would correspond to DICs and the lot size would represent an annual strip (e.g. 20 MW).

Note that the 20 MHz bars are twice as wide as the 10 MHz bars so the area of the bar matches up to revenues at the time indicated. Bidders are represented by different colours with the two largest bidders being T-Mobile (turquoise) and Verizon (red).

A closer examination of Figure 1 reveals that by the end of day five, the F block has already reached its final price. However, at that stage the A block is less than one twentieth the price of the F block. The reason for such a price differential has to do with substitution difficulties as pointed out by Cramton (2009, p. 9):

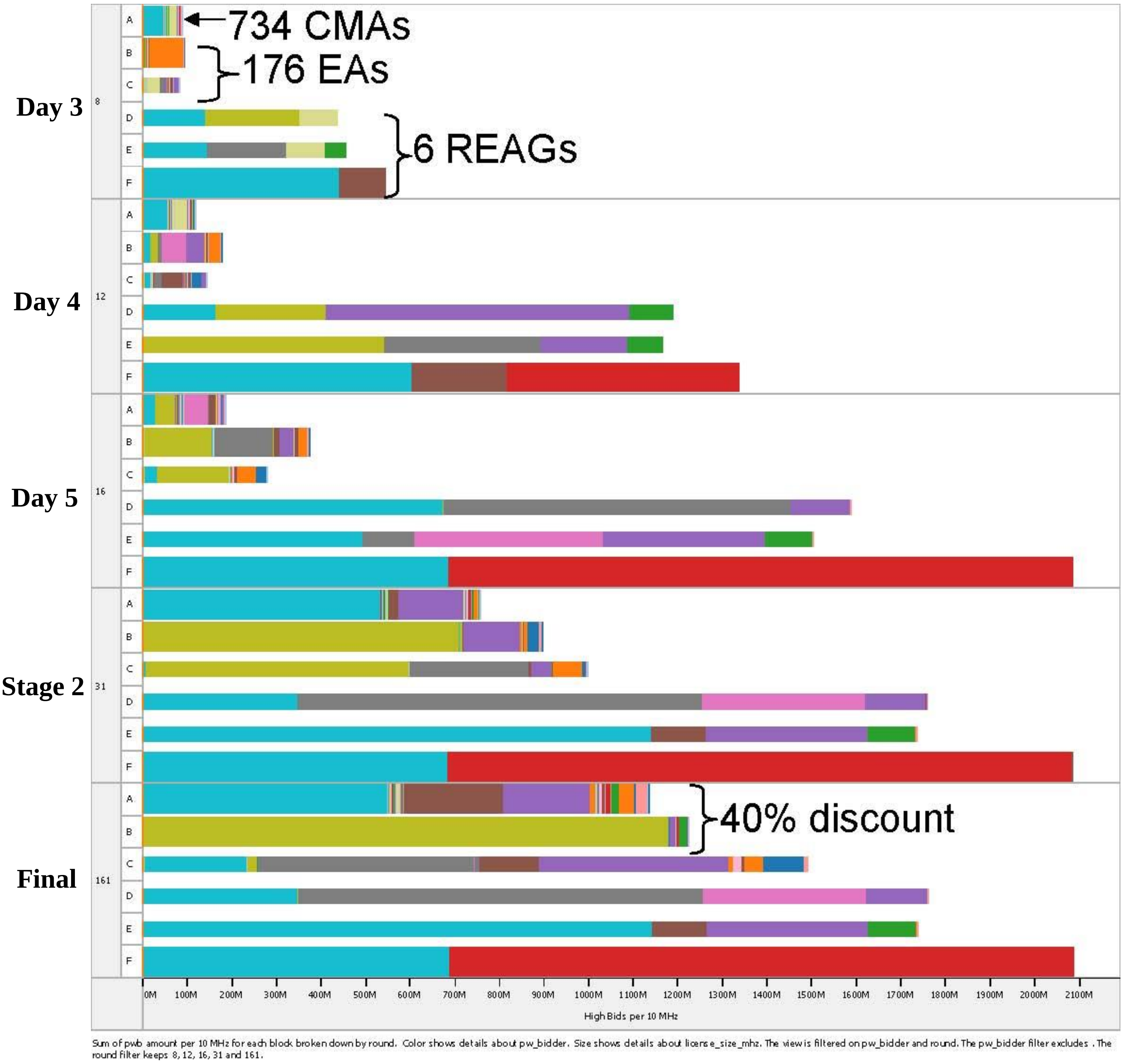
> *When Verizon is bumped off a large F block licence, it is easy for Verizon to substitute down to the A block, submitting say the 100 or so bids on the A lots that roughly cover the corresponding F lot. The problem is that once shifting down it would be nearly impossible to shift back up to F. The reason is that in subsequent*

[26] The analysis in this appendix is based on Crampton, P, 2013, "Spectrum Auction Design", *Review of Industrial Organization,* vol. 42, no. 2, , available at http://www.cramton.umd.edu/papers2005-2009/cramton-spectrum-auction-design.pdf.

rounds Verizon would only be bumped from some of the corresponding A block lots. Verizon would have to withdraw from many A lots in order to return to F, exposing itself to large withdrawal penalties.

This recent experience highlights that while SMR auctions have performed well in simple situations with a single geographic scheme, they can lead to potentially inefficient allocation in complex settings.

Figure 1 US AWS Auctions.



Reproduced from Cramton (2013)[27]

[27]Crampton, P, 2013, "Spectrum Auction Design", *Review of Industrial Organization,* vol. 42, no. 2, , available at http://www.cramton.umd.edu/papers2005-2009/cramton-spectrum-auction-design.pdf.