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800 MHz Auction

Final Report

NERA

Economic Consulting

NERA Economic Consulting
15 Stratford Place
London W1C 1BE
United Kingdom
Tel: +44 20 7659 8500
Fax: +44 20 7659 8501
www.nera.com

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1. Introduction

In this draft final report, NERA presents recommendations for the upcoming 800 MHz award in Sweden. The report contains our recommendations on auction format, detailed auction rules, and implementation issues.

Our methodology for developing detailed auction rules follows a four step procedure. First, we identify the constraints and objectives that form the basis for selecting an auction format. Second, we produce a shortlist of candidate auction formats. Third, we identify our recommended auction format from the shortlist. Fourth, we develop detailed auction rules for the recommended auction format.

1.1. Structure of the Report

The report is structured as follows:

- Section 2 contains an overview of the constraints and objectives that form the basis for selecting an auction format for the 800 MHz award. Based on the constraints and objectives we develop a shortlist of candidate auction formats.
- Section 3 contains an overview of each of the auction formats on our shortlist of candidate auction formats. We highlight pros and cons for each auction format.
- Section 4 contains our recommendation regarding auction format for the 800 MHz award. The recommendation is motivated by an assessment of pros and cons for each of the shortlisted candidate auction formats.
- Section 5 contains detailed auction rules for the recommended auction format. This section could form the basis for an Information Memorandum which will be issued to bidders.
- Section 6 contains a discussion of key properties of the auction rules for the recommended auction format.
- Section 7 contains a discussion of implementation issues.

2. Candidate Auction Formats

This section presents a list of candidate auction formats that are suitable for the 800 MHz award. We begin by detailing the constraints and objectives that provide the guidance for producing a shortlist of candidate auction formats. Each of the shortlisted candidate auction formats are then discussed in greater detail with the aim of highlighting pros and cons with respect to the 800 MHz award.

2.1. Constraints and Objectives

Substantial work on the 800 MHz has already been completed by PTS. Table 2.1 below provides a list of constraints that are the result of decisions that has been made. The table also lists some immediate implications for the choice of auction format.

Table 2.1
Constraints

Constraint	Implications for Auction Format
Spectrum Blocks:	
The 800 MHz band will be divided into six spectrum blocks, FDD1 to FDD6. Each spectrum block consists of 2*5 MHz paired spectrum.	It is our understanding that all bidders will want to buy at least two contiguous spectrum blocks, provided prices are low enough. However, many bidders will likely accept one spectrum block if the prices become too high. The spectrum blocks are therefore both substitutes and complements. Spectrum blocks are complements when two contiguous spectrum blocks are valued substantially higher than two separated spectrum blocks, or one spectrum block. Spectrum blocks are substitutes when two contiguous spectrum blocks can be substituted for two different contiguous spectrum blocks, although different pairs of spectrum blocks may not be perfect substitutes. For the efficiency of the auction outcome, it is important that the auction format allows bidders to express such preferences. Each of the candidate auction formats we have shortlisted does this, in different ways.
Spectrum Cap:	
A spectrum cap of two spectrum blocks (2*10 MHz) will be enforced in the auction.	Spectrum caps are imposed in most spectrum auctions. Each of the candidate auction formats we have shortlisted allows for a spectrum cap to be imposed.
Technical Requirements:	
The value of each spectrum block will be different. This is due to the different technical requirements to protect broadcasting use in Sweden and in neighbouring countries.	The fact that value of individual spectrum blocks differ implies that the auction format should allow for different prices of the different spectrum blocks, in order to facilitate an efficient allocation. Each of the candidate auction formats we have shortlisted allows for different prices.

Coverage Requirements:	
One spectrum block will have coverage requirements.	For the purpose of producing a shortlist of auction formats, we are leaving coverage requirements aside. For present purposes, coverage requirements are viewed as technical requirements that may affect the value/price of the spectrum blocks that have coverage requirements imposed.
Reserve Price:	
Reserve prices will be used in the auction. Reserve prices are yet to be determined, and may differ between spectrum blocks.	If no bidder places a bid that meets the reserve price for a spectrum block, the spectrum block will remain unsold. Different technical requirements (and coverage obligations) imply that reserve prices may differ between spectrum blocks. Each of the candidate auction formats we have shortlisted allows for different reserve prices.

In addition to the constraints outlined in Table 2.1 above, the choice of auction format will also be guided by the objectives of PTS, as outlined in Table 2.2 below.

Table 2.2
PTS Objectives

PTS Objective	Implications for Auction Format
The spectrum blocks should be awarded as contiguous blocks.	An auction outcome where some bidders are awarded two spectrum blocks that are not contiguous would be seen as an inefficient outcome. Each of the candidate auction formats we have shortlisted has features that promote/facilitate an outcome where bidders are awarded contiguous spectrum blocks. The candidate auction formats achieves this in a different ways.
Entry barriers should be minimised.	While most bidders will be interested in two spectrum blocks, some bidders may only be interested in one spectrum block when prices become too high. The auction format should allow for participation of both types of bidders in order to attract the largest number of bidders. The candidate auction formats we have shortlisted all allow for bidders to bid on one/two spectrum blocks. Also,
The auction process should be transparent and fair.	Sealed bid auctions and sequential auctions suffer from potential inefficiencies. With these auction formats, bidders may want to change their bids after seeing the auction outcome, but they are not able to do so. Each of the candidate auction formats we have shortlisted are based on simultaneous auction of spectrum blocks over multiple rounds.

2.2. Shortlist of Candidate Auction Formats

This section presents our shortlist of candidate auction formats that are suitable for the 800 MHz award.

Our first observation is that auction formats that can be described as "simultaneous multiple round auctions", have properties that match the objectives of PTS to assign the spectrum blocks in an efficient and transparent way. In particular, simultaneous multiple round auctions have the following two key features:

- Key feature #1: Simultaneous allocation of all spectrum blocks
- Key feature #2: Bidding in multiple rounds

These two key features together imply that simultaneous multiple round auctions allow bidders to react to price information during the auction by placing their bids on the spectrum blocks that is best suited for them. For example, a bidder may initially compete for FDD1 and FDD2, but as the auction reveals the price difference between these spectrum blocks and other spectrum blocks, the bidder has the opportunity to switch and bid instead on FDD3 and FDD4, for example. This process of increasing bids and switching between spectrum blocks promotes an efficient allocation of the spectrum blocks.

The advantages of a simultaneous multiple round auction format in the context of the 800 MHz award can also be highlighted by considering auction formats that depart from the two key features:

- *Sequential auctions (departing from key feature #1)*: This auction format contemplates auctioning each spectrum block one after the other. For example, FDD1 could be auctioned first, and bidders would have to make a decision on whether to purchase this spectrum block in advance of knowing the prices that will be reached by the remaining spectrum blocks. Bidders must make irrevocable decisions of whether to purchase the earlier auctioned spectrum blocks without the benefit of price information about the later auctioned spectrum blocks. A bidder may refrain from bidding on FDD1 and FDD2 in early auctions, in anticipation of lower prices of FDD3 and FDD4 in later auctions. However, if the prices of FDD3 and FDD4 turn out to be higher than anticipated, the bidder may regret not having bid on FDD1 and FDD2. This kind of inefficiency in the allocation of spectrum blocks is avoided in simultaneous multiple round auctions by closing the bidding on all spectrum blocks simultaneously.
- *Sealed bid auctions (departing from key feature #2)*: This auction format contemplates receiving a single round of bids for all spectrum blocks. This auction format would require potentially complicated rules to ensure that all spectrum blocks are awarded. Without these rules, a possible outcome is that all bidders submit bids for the same spectrum blocks. The sealed bid format requires bidders to form price estimates for all spectrum blocks before any bidding takes place and to place bids that are based on these estimates rather than bidding in response to the prices that the other bidders are willing to bid. As a result, this auction format places a heavy burden on bidders in terms of preparing their bids and creates considerable uncertainty. The winning bidder may not be the bidder that values the spectrum blocks the most, but rather the bidder that is most aggressive in discounting the uncertainty. As a result, the spectrum blocks may not be efficiently allocated.

Table 2.3 provides an overview of the advantages of the simultaneous multiple round auctions relative to sequential auctions and sealed bid auctions. The fist three criteria (price discovery, simplicity for bidders, and efficiency of auction outcome) all point towards simultaneous multiple round auctions as the most suitable category of auction format.

The last criterion (robustness to lack of competition) has been included to illustrate why sequential auctions or sealed bid auctions are sometimes observed despite their properties. For example, when auction revenue is a concern due to lack of competition, a sealed bid auction may be preferable. A simultaneous multiple round auction could result in auction prices being equal to reserve prices when the number of bidders is equal to the number of licenses (assuming that bidders can only win one license each). In effect, the auction would end after one bidding round. In contrast, bidders in a sealed bid auction, where the number of bidders is not known to bidders, would have to be more cautious and submit competitive bids. Only after the auction has been concluded will it be clear to bidders that a bid at the reserve price would have been sufficient. As a result, sealed bid auctions may be preferred in some scenarios where efficiency of the auction outcome is not the prime objective.

Table 2.3
Overview of Categories of Auction Formats

	Simultaneous Multiple Round Auctions	Sequential Auctions	Sealed Bid Auctions
Price Discovery	**P** Bidders can react to price formation for individual spectrum blocks as well as relative prices.	**O** Bidders will not see prices for later auctioned spectrum blocks until the auction for earlier auctioned spectrum blocks has been concluded.	**O** Bidders cannot react to price information. Bidders will only learn prices of spectrum blocks after the auction has ended.
Simplicity for Bidders	**P** Bidders only have to accept/reject prices announced by auction manager.	**O** Bidders will have to predict prices for later auctioned spectrum blocks before bidding for early auctioned spectrum blocks.	**O** Bidders will have to predict prices for all spectrum blocks before placing bids.
Efficiency of Auction Outcome	**P** The auction for all spectrum blocks closes simultaneously. Bidders see all prices before the auction ends.	**O** Bidders may get their price predictions for later auctioned spectrum blocks wrong.	**O** Bidders may get their price predictions wrong.

Robustness to Lack of Competition	**PO** Works well with sufficient competition. May end with final prices close to reserve prices otherwise.	**PO** If possible to hide the number of bidders, auction prices may be higher than reserve prices.	**PO** If possible to hide the number of bidders, auction prices may be higher than reserve prices.

Based on the discussion of constraints and objectives above, and the properties of the different categories of auction formats, we have restricted our shortlist of candidate auction formats to auction formats within the category of simultaneous multiple round auctions. Our shortlist is as follows:

1. **SMRA**

   Our first candidate auction format is a simultaneous multiple round auction where standing high bids cannot be switched to different spectrum blocks. This is sometimes referred to as the standard SMRA, which was initially developed for auctions of substitutes only. As a result, the auction format does not have ideal properties for the 800 MHz award. We include it mainly because it serves as a reference point, and our next two auction formats on the shortlist are both based on the SMRA.

2. **SMRA+S**

   Our second candidate auction format is a simultaneous multiple round auction with flexible switching rules. This auction format is based on the SMRA and the key difference is that standing high bids can be switched to different spectrum blocks. This flexibility in the switching rule reduces the risk of an auction outcome where one or more bidders will be awarded non-contiguous spectrum blocks.

3. **SMRA+C**

   Our third candidate auction format is a simultaneous multiple round auction with combinatorial (or package) bids. This auction format is based on the SMRA and the key difference is that bidders can place bids on packages of spectrum blocks as well as individual spectrum blocks. A bidder who places a bid on a package of spectrum blocks will either be awarded the full package, or none of the spectrum blocks contained in the package. This flexibility in the ‘bidding language’ reduces the risk of an auction outcome where one or more bidders will be awarded non-contiguous spectrum blocks.

4. **CCA**

   Our fourth and final candidate auction format is a combinatorial clock auction. This format can be viewed as a simplification of the SMRA+C since bidders are initially placing bids on generic spectrum blocks (i.e. all spectrum blocks have the same price), and combinatorial bids on specific spectrum blocks (with different prices) are only allow at the end of the auction.

3. Overview of Candidate Auction Formats

This section provides an overview of the four auction formats in our shortlist above. For each auction format, we discuss "how it works", its main advantages and its main disadvantages.

3.1. Simultaneous Multiple Round Auction (SMRA)

Our first candidate auction format is a simultaneous multiple round auction where standing high bids cannot be switched to different spectrum blocks. This is sometimes referred to as the standard SMRA, which was initially developed for auctions of substitutes only. As a result, the auction format does not have ideal properties for the 800 MHz award. We include it mainly because it serves as a reference point, and our next two auction formats on the shortlist are both based on the SMRA.

The SMRA format has been used for spectrum auctions worldwide on many occasions since it was introduced by the FCC in 1994 for its auction of 10 paging licenses.[1] The FCC alone has conducted in excess of 70 spectrum auctions using the SMRA format.

How it Works:

§ Each of the six spectrum blocks has its own individual price in each round, the going price. In the first round the going price of each spectrum block is the reserve price.

§ Bidders can place bids at the going prices on no more than two spectrum blocks (due to the spectrum cap) in each round.

§ After each round, a standing high bidder is identified for each spectrum block (unless a spectrum block has received no bids, in which case it remains unsold). When more than one bidder has placed a bid at the going price on a spectrum block, the standing high bid is chosen at random.

§ A bidder who has the standing high bid on a spectrum block cannot change his bid (until a new and higher bid has been placed on the spectrum block by another bidder).

§ A bidder who has a bid on a spectrum block that is not the standing high bid has the following options:

- The bid can remain unchanged.
- The bid can be increased.
- The bid can be switched to another spectrum block.

§ Bidding is subject to activity and eligibility requirements. In order to maintain eligibility, a bidder has to be active. A bidder is active when a new bid is placed, either as an increased bid on the same spectrum block, or as a switched bid on a different spectrum block. A bidder is also active when a bid is the standing high bid. A bidder who is not

[1] A key reference to the SMRA format is: "Putting Auction Theory to Work: The Simultaneous Ascending Auction", Paul Milgrom, Journal of Political Economy, 2000, volume 108, no. 2.

active will loose eligibility to place bids. When all eligibility is lost, the bidder has effectively withdrawn from the auction.

- The auction closes in the round when no new bids are placed. Winning bids are the standing high bids when the auction closes.

Main Advantages:

The main advantage of the SMRA format for six spectrum blocks is that it is very simple for bidders to understand the auction rules. Whenever a bid is outbid, the bidder will have to increase the bid or switch to a different spectrum block (in order to maintain eligibility to place bids). As a result, the price for each spectrum block can only increase during the auction and the scope for strategic bidding is very limited.

For example, since all bids are potentially winning bids (a standing high bid may never be outbid, and such a bid cannot be switched), excessive switching back and forth between spectrum blocks would be a very risky strategy. A bidder who is not prepared to win a particular spectrum block should not place a bid on such a spectrum block. The development of prices under the SMRA format will therefore to a greater extent reflect valuations, relative to the development of prices under the SMRA+S format, as explained in section 3.2 below.

Main Disadvantages:

The main disadvantage of the SMRA format for six spectrum blocks is that bidders are not able to place a bid on a pair of two contiguous spectrum blocks. A bidder who is placing a bid on FDD1 and FDD2, for example, may be selected as standing high bidder on FDD1 only. As long as the bidder has the standing high bid on FDD1, he cannot switch his two bids to FDD3 and FDD4, for example. In other words, the bidder is faced with the possibility of being awarded only one of the two spectrum blocks he was bidding on. This is typically referred to as the ‘exposure problem’.

One way of dealing with the exposure problem under the SMRA format is to simply bundle the spectrum blocks into larger licenses, for example three licenses of two contiguous spectrum blocks each. However, in order to do this, PTS would need to assess which packages of spectrum bidders would be interested in. When some bidders may want only one spectrum block, such an approach would be highly restrictive, and it would contradict the stated objective of facilitating entry of different types of bidders.

Bundling of spectrum blocks would only be recommended if demand for single spectrum blocks can be ruled out. If this is the case, it follows that bidders want <u>at least two</u> spectrum blocks. Moreover, the spectrum cap implies that bidders can win <u>at most two</u> spectrum blocks. All bidders would therefore be interested in <u>exactly two</u> spectrum blocks. By auctioning bundles of spectrum blocks, it is assured that bidders will only be awarded contiguous spectrum blocks.

Note that the argument for bundling spectrum blocks would be very different if the spectrum cap was not set at two spectrum blocks. If the spectrum cap was four spectrum blocks, some bidders may want to bid on four blocks, other bidders may want three blocks, and some bidders may only want two blocks. In such a case, the flexibility offered by auctioning spectrum blocks of 2x5 MHz rather than bundles of 2x10 MHz implies that bidders can decide how much spectrum they want, depending on the prices that emerge during the auction. With a spectrum cap of two, such flexibility is redundant, unless there are bidders who want one spectrum block of 2x5 MHz.

3.2. Simultaneous Multiple Round Auction (SMRA+S)

Our second candidate auction format is a simultaneous multiple round auction with flexible switching rules. This auction format is based on the SMRA and the key difference is that standing high bids can be switched to different spectrum blocks. This flexibility in the switching rule reduces the risk of an auction outcome where one or more bidders will be awarded non-contiguous spectrum blocks.

The SMRA+S format has been used for spectrum auctions in Finland, Norway and Sweden on several occasions, although with slightly different pricing rules.[2] In Sweden the SMRA+S format has been used successfully for auction of FWA licenses in 2007 and auction of 2.6 GHz licenses in 2008.

How it Works:

§ Each of the six spectrum blocks has its own individual price in each round, the going price. In the first round the going price of each spectrum block is the reserve price.

§ Bidders can place bids at the going prices on no more than two spectrum blocks (due to the spectrum cap) in each round.

§ After each round, a standing high bidder is identified for each spectrum block (unless a spectrum block has received no bids, in which case it remains unsold). When more than one bidder has placed a bid at the going price on a spectrum block, the standing high bidder is chosen at random.

§ In each round, bidders have the following options:

  – A bid on a spectrum block can remain unchanged.
  – A bid on a spectrum block can be increased if the previously placed bid is not the standing high bid.[3]
  – A bid on a spectrum block can be switched to another spectrum block.

§ Bidding is subject to activity and eligibility requirements. In order to maintain eligibility, a bidder has to be active. A bidder is active when a new bid is placed (either an increased bid on the same spectrum block, or a switch to a different spectrum block), and when a bid is the standing high bid. In the first round, all bidders are eligible to bid on two spectrum blocks. Eligibility remains at two as long as bidders are active on two spectrum blocks, and eligibility is reduced to one (zero) when bidders are only active on one (zero) spectrum blocks).

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[2] The SMRA+S format was developed by Prof. Niels-Henrik M von der Fehr of University of Oslo in conjunction with NPT.

[3] In some SMRA+S auctions, the bidder with the standing high bid may also increase his bid for the spectrum block, by placing a bid at the going price. We address this issue in Section 6.4 below.

- A bid that is not active (hence the bidder has lost eligibility) may become reactivated. This happens when all bids at higher prices on the spectrum block have been switched to a different spectrum block. A reactivated bid becomes the standing high bid on the spectrum block, and the bidder regains his eligibility associated with that bid.

- The auction closes in the round when no new bids are placed and no bids are reactivated. Winning bids are the standing high bids when the auction closes.

Main Advantages:

The main advantage of the SMRA+S format is that it is relatively simple for bidders to understand the auction rules. Furthermore, this format has been used successfully in Sweden on two occasions: Auction of FWA licenses in 2007 and auction of 2.6 GHz licenses in 2008. Swedish bidders are therefore familiar with the auction format.

The simplicity of the auction format stems from the fact that the exposure problem (bidders may be awarded only some of the spectrum blocks it desires) has been dealt with simply by allowing standing high bidders to switch the bid. Should a bidder who desires both FDD1 and FDD2 find himself as standing high bidder on only FDD1, both bids can be switched to FDD3 and FDD4 for example. This, in turn, reduces the risk of an outcome where one or more bidders will be awarded non-contiguous spectrum blocks.

Main Disadvantages:

The main disadvantage from the SMRA+S format is that the exposure problem has been reduced, but not completely eliminated. While a bidder, who has the standing high bid on FDD1, and not a standing high bid on FDD2, is free to switch both bids to FDD3 and FDD4 for example, the bidder may not be able to do so if the prices of FDD3 and FDD4 are too high. Bidders are therefore always somewhat exposed although the exposure has been greatly reduced compared with rules that prevent standing high bidders to switch (e.g. the SMRA format).

Another disadvantage from the SMRA+S format is that the pricing rule becomes critical. For example, if a bidder is switching a bid from FDD1 to FDD3 and in a later round wants to switch back to FDD1, what price should the bidder be forced to accept for FDD1? Should it be one bid increment above the current standing high bid on FDD1, or should it be one bid increment above the bidder's own previous bid on FDD1?

In the former case, there is a risk that the auction may never end. Cyclical behaviour in the prices can occur since the going price of a spectrum block may decrease (when the standing high bidder switches away from the spectrum block). After the price of a spectrum block has decreased it may be bid up again, and the cycle could repeat itself without any real progress in the auction. For this reason, it is desirable to have a requirement that forces bidders to accept a going price that is one bid increment higher than the bidder's own previous bid on the spectrum block. However, this also means that bidders may face different going prices for the same spectrum block (depending on past bidding history). When bidders face different prices for the same spectrum block, efficiency of the auction outcome is no longer assured. We revert to this issue in section 6.3 below.

3.3. Simultaneous Multiple Round Auction (SMRA+C)

Our third candidate auction format is a simultaneous multiple round auction with combinatorial (or package) bids. This auction format is based on the SMRA and the key difference is that bidders can place bids on packages of spectrum blocks as well as individual spectrum blocks. A bidder who places a bid on a package of spectrum blocks will either be awarded the full package, or none of the spectrum blocks contained in the package. This flexibility in the 'bidding language' reduces the risk of an auction outcome where one or more bidders will be awarded non-contiguous spectrum blocks.

How it Works:

- Each of the six spectrum blocks has its own individual price in each round, the going price. In the first round the going price of each spectrum block is the reserve price.
- Bidders are also allowed to place bids on packages of two contiguous spectrum blocks. Each of these packages of spectrum blocks will also have an individual price.[4]
- After each round, a set of provisionally winning bids is identified. This set consists of the combination of bids that is both feasible and revenue maximising. A set of bids is feasible if the set does not contain overlapping bids, i.e. a bid on FDD1 and a bid on a package of FDD1+FDD2 cannot both be in the provisionally winning set of bids. The determination of provisionally winning bids is analogous to determining standing high bids in the SMRA format.
- A bidder who has a bid in the provisionally winning set of bids cannot change his bid until his bid has been replaced in the provisionally winning set of bids by another bid.
- A bidder who has a bid that is not in the set of provisionally winning bids has the following options:
  - The bid can remain unchanged.
  - The bid can be increased.
  - The bid can be switched to another spectrum block or package of spectrum blocks.
- Bidding is subject to activity and eligibility requirements. In order to maintain eligibility, a bidder has to be active. A bidder is active when a new bid is placed, either as an increased bid on the same spectrum block, or as a switched bid on a different spectrum block. A bidder is also active when a bid is in the set of provisionally winning set of bids. A bidder who is not active will loose eligibility to place bids. When all eligibility is lost, the bidder has effectively withdrawn from the auction.
- The auction closes in the round when no new bids are placed. Winning bids are the bids in the set of provisionally winning bids when the auction closes.

[4] In principle, bidders could be allowed to place bids on all possible packages of spectrum blocks that satisfy the spectrum cap. However, to simplify matters, we rule out packages that consist of non-contiguous spectrum blocks.

Main Advantages:

The main advantage of the SMRA+C format is that it deals with the exposure problem in a very direct way. Under the SMRA+C format, it is not possible for bidders to be awarded part of a bid on a package of spectrum blocks. The exposure problem has therefore been completely eliminated.

Another advantage of the SMRA+C format is that it is a relatively straight forward extension of the SMRA format, which most bidders are familiar with. Also, while the SMRA+C in some cases would be extremely complex and computationally burdensome, the format remains tractable for the 800 MHz award. This is due to the rather limited number of spectrum blocks and the spectrum cap that rules out packages of more than two spectrum blocks. In other auctions with more spectrum blocks and a less strict spectrum cap, the number of different packages (and hence prices) can quickly become very large.[5]

Main Disadvantages:

The main disadvantage of the SMRA+C format is that the auction has eleven prices, one price for each of the six individual spectrum blocks and one price for each of the five possible packages of two contiguous spectrum blocks. The problem with this number of prices is that there is no unique way of determining the relationship between a price of a package and the prices of the individual spectrum blocks that make up the package. As a result, the auction may give rise to a ‘threshold problem’.

The threshold problem in auctions with package bidding refers to the difficulty two bidders who want single spectrum blocks may have in outbidding a single bidder who wants a package of the two spectrum blocks. Consider an example where bidder A is interested in FDD1 only, and bidder B is interested in FDD2 only. Both bidders are willing to pay SEK 14,000,000 for the spectrum block. Furthermore, bidder C wants a package of both spectrum blocks (FDD1+FDD2) and is willing to pay SEK 20,000,000 for the package. Note that with these valuations, the efficient allocation is to award FDD1 to bidder A and award FDD2 to bidder B. This allocation generates a surplus of SEK 28,000,000 or SEK 8,000,000 more than the surplus generated by awarding the package to bidder C. This example can be used to illustrate the threshold problem under the SMRA+C format.

Suppose bidder A and bidder B have bid SEK 5,000,000 for FDD1 and FDD2 respectively, and that bidder C has bid SEK 20,000,000 for the package of FDD1+FDD2. The provisionally winning bid is thus the package bid for FDD1+FDD2, which bidder C placed. Neither bidder A nor bidder B can single-handedly overcome the difference (the threshold) between the current provisionally winning bid and a bid that would change the set of provisionally winning bids. Doing so would require bidder A to bid at least SEK 15,000,000 (given bidder B is bidding SEK 5,000,000). The same goes for bidder B. However, coordinated bid increases would allow bidders A and B to bid SEK 10,000,000 each (plus one bid increment) and have their bid selected for the provisionally winning set.

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[5] This issue is often referred to as the NP-completeness of the winner determination problem.

The key insight from this example is that an efficient auction outcome may require unusually large bid increments on single spectrum blocks in order to reduce the threshold problem. However, at the same time, such large price increments may deter bidders who are competing for single spectrum blocks from bidding. In other words, there is a trade-off between overcoming threshold problems and ensuring a reasonable pace of the auction.

The threshold problem also spills over to other aspects of the auction rules, in particular activity rules. Ideally, PTS wants to allow bids that do not replace the provisionally winning set in order to address threshold problems. Therefore, activity rules can be specified such that they give full credit to non-provisionally winning bids as well as provisionally winning bids. Again, this involves a trade-off between addressing the threshold problem and assuring pace of the auction.

Since the threshold problem is inherently a free-rider problem, there is a danger that even with appropriately designed activity rules and bid increments, bidders hold back bidding. Closing rules that allow two rounds of no new provisionally winning bids may therefore be considered.

The SMRA+C format is sometimes hailed as superior to the SMRA format because it allows for combinatorial bidding, which the SMRA format does not. However, this flexibility comes at a high price, which is complexity. The added complexity means that most practical applications of combinatorial auctions are designed as "reasonable approximations". In the CCA format we discuss in the next section, the grouping of spectrum blocks is an example of such an approximation/simplification.

3.4. Combinatorial Clock Auction (CCA)

Our fourth and final candidate auction format is a combinatorial clock auction. This format can be viewed as a simplification of the SMRA+C since bidders are initially placing bids on generic spectrum blocks (i.e. all spectrum blocks have the same price), and combinatorial bids on specific spectrum blocks (with different prices) are only allow at the end of the auction.

This auction format has been planned for use in spectrum auctions in Netherlands, the UK and Denmark. What these auctions have in common is that both TDD and FDD spectrum blocks are offered for sale, and the band plan (the division between TDD and FDD) is determined in the auction. As we will discuss below, the CCA format is designed with an endogenous band plan in mind (at the expense of price revelation), hence the format is less suitable for the Swedish 800 MHz award since only FDD blocks are offered for sale.

The main reason for including the CCA in our shortlist of candidate auction formats is that is has been widely recommended for auctioning the 'digital dividend' spectrum, for the reasons stated above.[6]

How it Works:

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[6] See e.g. "Auctioning the Digital Dividend", Peter Cramton, 2008.

- Six spectrum blocks are auctioned: FDD1, FDD2, FDD3, FDD4, FDD5 and FDD6. Bidders are also allowed to place bids on packages of spectrum blocks that satisfy the spectrum cap, i.e. any package that contains no more than two spectrum blocks.
- Spectrum blocks are grouped such that each group of spectrum blocks contain similar blocks. During the primary stage of the auction, each group of spectrum blocks will have one price (i.e. at this stage bidders are not able to bid on specific blocks, they are bidding on generic blocks within each group).
- The primary stage consists of primary rounds (much like the SMRA format) where bidders indicate how many spectrum blocks they want within each group. The prices are raised until there is no excess demand within any group. At this stage, it has been determined how many spectrum blocks each bidder will win. It has not been determined which specific spectrum blocks each bidder has won.
- In the assignment stage, bidders can place bids on packages of specific spectrum blocks, under the constraint that no bidder can win more spectrum blocks than he was awarded during the primary stage. The purpose of the assignment stage is to assign specific spectrum blocks within each group of spectrum blocks. The assignments stage consists of one round of sealed bids.

Main Advantages:

The main advantage of the CCA format is that it allows bidders to construct precisely the packages of spectrum blocks they want to bid on (in the assignment stage). For example, a bidder who is bidding on a package that consist of FDD1 + FDD2, will either be awarded both spectrum blocks, or none of the spectrum blocks. The exposure problem has therefore been completely eliminated.

Main Disadvantages:

The main disadvantage of the CCA format is that price revelation is severely limited by the grouping of spectrum blocks during the primary stage of the auction. Typically, the CCA format is used in auctions where there are both TDD blocks and FDD blocks, and the two types of spectrum blocks are then divided into two groups. This means that during the primary stage there are only two prices, one for TDD blocks and one for FDD blocks.

In this type of auction there is an additional role for the combinatorial bids (beyond reducing the exposure problem), which is to determine the band plan. For example, while the total amount of spectrum may be fixed, the split between FDD and TDD blocks would be determined in the auction, depending on the two prices for FDD and TDD blocks. This issue is not present for the 800 MHz award.

For the 800 MHz award in Sweden, there are six different FDD blocks, and it is not clear how these blocks could meaningfully be divided into homogeneous groups. The characteristics of the FDD blocks differ to an extent such that having them as one group would imply that all meaningful uncertainties about relative prices would be deferred until the sealed bid assignment stage. In other words, bidders are not able to switch between FDD blocks over multiple rounds where relative prices emerge. This is a severe limitation of the CCA format.

A further problem with the CCA format is the pricing rule in the assignment stage, which involves a tension between Vickrey pricing and core pricing, as discussed in "A New Payment Rule for Core-Selecting Package Auctions", Paul Klemperer, 2009. In short, Vickrey pricing implies that bidders' dominant strategies are to bid their actual valuations for the spectrum blocks as opposed to core pricing where deviations from truthful bidding are profitable. However, Vickrey pricing can lead to very low revenues, and introduces collusive possibilities that are hard to guard against. As a result, Ofcom has implemented a pricing rule that is a trade-off between Cickrey and core pricing.

4. Recommended Auction Format

This section presents our recommended auction format for the 800 MHz award. We start by tabulating our shortlist of candidate auction formats against a list of selection criteria which is based on the constraints and objectives we outlined in section 2 above.

Table 4.1
Evaluation of Candidate Auction Formats

Auction Format	Efficiency of Auction Outcome	Simplicity for Bidders	Implementation Costs
SMRA	**O** The SMRA format, where standing high bids cannot be changed, implies that the exposure problem may be severe. As a result, the auction outcome may not be efficient.	**P** The SMRA format is very simple for bidders. Bidding is straightforward and transparent.	**P** The SMRA format has low implementation costs for PTS. The format is a simplification of the SMRA+S format that has been used successfully by PTS in past auctions.
SMRA+S	**PO** The SMRA+S format has properties (flexible switching rule), which facilitates an efficient outcome. However, the format cannot guarantee efficiency.	**P** The SMRA+S format is relatively simple for bidders. Bidding is straightforward and transparent.	**P** The SMRA+S format has low to medium implementation costs for PTS. The format has been used successfully by PTS in past auctions.
SMRA+C	**PO** The SMRA+C format allows bidders to place bids on packages of spectrum blocks, which eliminates the exposure problem. However, the auction format suffers from a potential threshold problem.	**O** The SMRA+C format is relatively complex for bidders. While bidding is straightforward, the complexity of the rules makes the auction less transparent.	**O** The SMRA+C format has high implementation costs for PTS. Depending on the specific auction rules, algorithms for winner determination and price determination can be fairly complex.
CCA	**PO** The CCA allows bidders to place bids on packages, which eliminates the exposure problem. However, price revelation is severely limited, which hinders an efficient allocation of FDD blocks.	**O** The CCA format is relatively complex for bidders. While bidding is straightforward, the complexity of the rules makes the auction less transparent.	**O** The CCA format has medium to high implementation costs for PTS. Depending on the specific auction rules, algorithms for winner determination and price determination can be fairly complex.

Table 4.1 provides the basis for a ranking of the four candidate auction formats:

1. SMRA+S
2. SMRA+C
3. CCA
4. SMRA

This ranking of candidate auction formats reflects a trade-off between efficiency (reducing the exposure problem) and simplicity. In the following paragraphs we will justify our recommendation by eliminating candidate auction formats one by one.

We don't see the SMRA format as a serious candidate for the 800 MHz award, mainly because it has poor efficiency properties due to the fact that standing high bids can't be switched. This poses a potentially serious exposure problem for bidders. The other three candidate auction formats deal with the exposure problem, although in different ways.

We also don't see the CCA format as a serious candidate for the 800 MHz award, mainly because it is designed for a different scenario. The CCA format is designed for a scenario where there are a limited number of groups of spectrum blocks, where spectrum blocks within each group are reasonably similar, for example two groups of FDD blocks and TDD blocks. With six FDD blocks that differ by technical constraints and coverage obligations, we don't see an obvious way of grouping the spectrum blocks. As a result, the CCA format would have poor price discovery properties relative to our two remaining candidates, the SMRA+C and the SMRA+S.

The SMRA+C and the SMRA+S formats are based on the simple SMRA format, but designed with exposure problems in mind. While the SMRA+C format allows package bids, the SMRA+S allow standing high bids to be switched. We have argued above that the SMRA+C format is relatively complex and suffers from the threshold problem, which makes the determination of going prices critical for efficiency properties. Moreover, there are few examples of implementations of the SMRA+C format. In contrast, the SMRA+S format has been used successfully for spectrum auctions in Finland, Norway and Sweden. As a result, we recommend that PTS should use the SMRA+S format for the 800 MHz award.

5. Detailed Auction Rules

This section contains detailed auction rules for the auction format we have recommended in Section 3 above: The SMRA+S format.

We have written the section in a style that could form the basis for an Information Memorandum, which will be published prior to the auction. The purpose of this section is to present the auction rules in a self-contained and coherent manner. This means that no references are made to other sections of this report, and terms are used consistently throughout the section.

5.1. Overview of Auction Format

The auction format is a Simultaneous Multiple Round Auction with flexible switching rules (SMRA+S). The auction format is called "simultaneous" because it assigns all six spectrum blocks together in a single process, and it is called "multiple rounds" because it can offer bidders multiple opportunities to place bids. For example, a bidder that would not be awarded a particular spectrum block on the basis of the results of a bidding round may increase its bid on the spectrum block or switch its bid to another spectrum block in the next round. Finally, the auction has flexible switching rules in the sense that all active bids (including standing high bids) can be switched to different spectrum blocks at all times.

Each bidder can place bids on at most two of the six spectrum blocks in a round. By placing a bid, the bidder indicates that it is willing to purchase the spectrum block at the going price, which is announced at the beginning of each round. A bid is a binding offer that may not be rescinded.

In the first round, bidders place their bids by indicating which particular spectrum block(s) the bidder is willing to purchase at the reserve price(s). If one or more bidders place a bid on a particular spectrum block, one bidder is selected as the standing high bidder (a provisional winner of the spectrum block). Further, if one or more bidders place a bid on a particular spectrum block, the going price for that spectrum block is increased in the second round.

In the second and all subsequent rounds, all bidders have up to three options for each of the bids that have previously been placed: A bidder can keep its bid on a spectrum block, a bidder can improve its bid on a spectrum block, and a bidder can switch its bid to a different spectrum block. Once a bidder has placed bids on (one) two spectrum blocks, the bidder will have binding bids on (one) two spectrum blocks throughout the auction. A bid on a spectrum block that is not the standing high bid may therefore become reactivated in case all bids at higher prices are switched away from the spectrum block.

The auction concludes in the round when no new bids are placed and no bids are reactivated. The final price for a particular spectrum block is the standing high bid for that spectrum block in the last round.

The detailed auction rules are described below.

5.2. Spectrum Blocks

Table 4.1 provides the reserve prices for each of the six spectrum blocks. The spectrum blocks are assigned different reserve prices, which reflect the different expected values of the spectrum blocks.

Table 4.1 also provides points assigned to each of the six spectrum blocks that are used for activity and eligibility calculations. All six spectrum blocks are assigned one point each.

Table 4.1
Spectrum Blocks

Block	MHz	Lower Band	Upper Band	Reserve Price	Points
FDD1	2x5 MHz	791-796 MHz	832-837 MHz	*(to be determined)*	1
FDD2	2x5 MHz	796-801 MHz	837-842 MHz	*(to be determined)*	1
FDD3	2x5 MHz	801-806 MHz	842-847 MHz	*(to be determined)*	1
FDD4	2x5 MHz	806-811 MHz	847-852 MHz	*(to be determined)*	1
FDD5	2x5 MHz	811-816 MHz	852-857 MHz	*(to be determined)*	1
FDD6	2x5 MHz	816-821 MHz	857-862 MHz	*(to be determined)*	1

5.3. Going Prices

The going price for each spectrum block is the price at which bidders can place a bid. In the first round the going prices are the reserve prices. In subsequent rounds, going prices will increase for spectrum blocks where one or more bids have been placed.

The pace at which going prices are increased is determined by the auction manager, PTS. The increase in a going price between two rounds is referred to as a bid increment. Bid increments may vary across spectrum blocks and bid increments need not stay constant throughout the auction.

The going price of a particular spectrum block may decrease in case the standing high bid is switched away from the spectrum block. In this case, a new (and possibly lower) standing high bid will be identified, and the going price will be the new (and possibly lower) standing high bid plus one bid increment. In case all bids are switched away from a spectrum block, the going price will revert to the reserve price.

It is a further restriction that a bidder can never place a bid on a spectrum block at a price which is lower than the price the bidder has previously bid on that spectrum block. A new bid on a spectrum block must always be at least one bid increment higher than any previous bid by that bidder on that spectrum block. The going price of a spectrum block may therefore differ between bidders.

5.4. Activity and Eligibility

In order to place a bid, each bidder must have sufficient eligibility points. In the first round, all bidders are endowed with two eligibility points. This reflects a spectrum cap of 2x10 MHz per bidder.

A bidder who places a bid on one spectrum block in the first round will have at most one eligibility point throughout the auction. A bidder who places bids on two spectrum blocks in the first round will have at most two eligibility points throughout the auction.

At the end of each round, eligibility points for the upcoming round are determined by activity in the current round. A bidder is deemed to be active on a spectrum block if:

- The bidder has the standing high bid, or
- The bidder has placed a bid at the going price in the current round.

A bidder who has two eligibility points will keep his two eligibility points if he is active on two spectrum blocks. The bidder will have his eligibility points reduced to one if he is only active on one spectrum block, and he will have his eligibility points reduced to zero if he is not active on any spectrum block.

Similarly, a bidder who has one eligibility point will keep his eligibility point if he is active on one spectrum block, and he will have his eligibility reduced to zero if he is not active on any spectrum block.

Eligibility points are tied to specific bids. For example, a bidder with two eligibility points, who is only active on one spectrum block, will keep the eligibility point that is associated with the bid on the spectrum block where the bidder is active.

The calculation of eligibility points is subject to the rules of reactivation (section 4.7) and waivers (section 4.8) outlined below.

5.5. Placing Bids

A bid for a spectrum block is a binding offer to buy the spectrum block at the going price. In the first round, bidders may place bids on up to two spectrum blocks. In subsequent rounds, bids may be placed in accordance with the following rules:

When a bid is the standing high bid on a spectrum block, the bidder has two options:

- The bid can be kept at the same spectrum block at the same price. The standing high bid cannot be increased.
- The bid can be switched to a different spectrum block. The switch is performed by cancelling the bid and placing a new bid at the going price on a different spectrum block where the bidder does not already have a bid.

When a bid is not the standing high bid on a spectrum block, and the bid carries eligibility, the bidder has three options:

- The bid can be kept at the same spectrum block at the same price. This implies that the bid will lose eligibility.
- The bid can be kept at the same spectrum block by placing a bid at the going price. This implies that the bid will not lose eligibility.
- The bid can be switched to a different spectrum block. The switch is performed by cancelling the bid and placing a new bid at the going price on a different spectrum block where the bidder does not already have a bid.

When a bid is not the standing high bid on a spectrum block, and the bid does not carry eligibility, the bid cannot be changed. The bid is however still binding and may become reactivated in accordance with section 4.7.

5.6. Standing High Bidder

At the end of each round, all bids are considered. The standing high bid on a spectrum block is the bid that has been placed at the highest price. If two or more bidders have placed a bid at the same price, the standing high bid is chosen at random. A standing high bid status is assigned to each spectrum block because if the auction were to end with no further bids, the standing high bid would be a winning bid.

5.7. Reactivation

A bid on a spectrum block that does not carry eligibility cannot be changed. However, if all bids at higher prices are switched away from the spectrum block, the bid will become reactivated. If two or more bids are candidates for reactivation (i.e. the bids have been placed at the same price), the bid that becomes reactivated is chosen at random.

A bid that has become reactivated carries eligibility and may therefore be changed in accordance with section 4.5.

A bidder who has a bid that becomes reactivated will also have his other bid reactivated, if such a bid exists (i.e. two bids were placed by the bidder in the first round) and if it doesn't already carry eligibility.

5.8. Waivers

Instead of placing bids, a bidder can use a waiver. When a bidder uses a waiver, the bidder will carry over its eligibility to the next round.

A waiver may be used by each bidder on no more than three occasions during the auction. It is not possible to use a waiver in the first round.

5.9. Information to Bidders

At the beginning of each round, bidders will receive information on the going price for each spectrum block and each bidder will also learn whether it has the standing high bid for any of the spectrum blocks.

In addition, as a measure of the progress of the auction, bidders will be informed if the sum of eligibility points for all bidders is higher/lower than a predetermined threshold. This threshold will depend on the number of bidders who register for the auction.

5.10. End of Auction

The auction concludes in the round when no bids are placed and no bidders are using a waiver. The bidder with the standing high bid for each spectrum block has won the spectrum block and the final price for each particular spectrum block is the standing high bid for that spectrum block in the last round.

6. Properties of Auction Rules

This section provides a discussion of some key features of the auction rules outlined above. While the SMRA+S format has some desirable features, as discussed in sections 2 and 3 above, we focus in this section on some of the caveats that apply to the specific auction rules of section 4.

6.1. Fragmented Outcome

The purpose of the flexible switching rule, where a standing high bid can be switched to a different spectrum block, is to minimise the risk of ending the auction with an allocation that is undesirable to bidders. If a bidder is bidding on two contiguous spectrum blocks, and the auction has an outcome where he is awarded only one spectrum block, it would be an example of an undesirable outcome.

For example, the flexible switching rule implies that if a bidder is placing bids on FDD1 and FDD2, and FDD2 becomes too expensive, he can switch both bids to FDD3 and FDD4. This can be done even when the bidder has a standing high bid on FDD1 and/or FDD2.

It is important to note that while the flexible switching rule implies that a bidder will always be offered the chance to switch, the offer may be too expensive to accept. In the example above where the bidder was not willing to bid at the going price of FDD2, the prices of FDD3-6 may also be too high. In such a case, the bidder would run the risk of winning FDD1 only.

Another feature of the auction rules which seek to minimise the risk of undesirable auction outcomes is the reactivation rule that ensures that a bidder who is reactivated on one bid also becomes reactivated on his other hid. The implication is that a bidder who withdraws from the auction will always be offered to place both his bids, should one of his bids become reactivated. As with the flexible switching rule, such an offer will only solve the problem if the offer is not too expensive to accept.

6.2. Eligibility Parking

As indicated in Table 4.1, we have associated one point with each spectrum block. This assumption reflects the fact that spectrum blocks are of roughly equal value. In case technical requirements (or coverage obligations) imply that values of the spectrum blocks will differ by a factor of two or more, we would recommend that points are adjusted accordingly.

For example, if one spectrum block is twice as valuable as another spectrum block, the more valuable spectrum block should be associated with two points. The reason for aligning points with expected value is that bidders should not be able to ‘park eligibility’ on relatively cheap spectrum blocks. Eligibility parking refers to a strategy where a bidder is maintaining his eligibility by placing bids on relatively cheap spectrum blocks, while waiting for other bidders to withdraw from the auction, and then towards the end of the auction the bidder switch to the more expensive spectrum blocks he is interested in. The effect of spectrum parking is that useful price revelation is hindered since bidders do not place sincere bids.

It should be noted that there are good reasons to keep points identical across spectrum blocks unless values differ considerably. For example, when FDD1 and FDD2 are substitutes, and only differ slightly in value, an assignment of different points to FDD1 and FDD2 would create an asymmetric switching restriction. Suppose FDD1 is associated with one point, and FDD2 is associated with two points. In this case a bidder can always switch his bid from FDD2 to FDD1, but the bidder cannot switch from FDD1 to FDD2 if he only has one eligibility point.

Furthermore, the incentives for eligibility parking are less strong under the SMRA+S format than under the SMRA format. The reason is that eligibility parking presumes that bidders who have withdrawn from the auction can never re-enter the auction. This is not the case under the SMRA+S format where bids may be reactivated when the 'parked eligibility' is switched. This implies that there are less strong arguments for deviating from equal points under the SMRA+S format.

6.3. Different Going Prices

The pricing rule we have recommended in the auction rules (see sections 5.3 and 5.5) involves the possibility of having different going prices for the same spectrum block.

Specifically, the rules require bidders to place a bid at the maximum of (i) the going price for bidders who have never had a bid on the frequency block, and (ii) the highest bid the bidder in question has previously placed on the frequency block plus one bid increment. Such a pricing rule could be labelled as a *discriminatory pricing rule.*

An alternative is a pricing rule that requires bidders who want to switch into a frequency block to place a bid at the going price, which is common for all bidders. Such a pricing rule could be labelled as a *uniform pricing rule.*

The discriminatory pricing rule was favoured over the uniform pricing rule in order to limit excessive switching, which may in fact cause the auction to never end. However, the discriminatory pricing rule also comes with a caveat. A problem with the discriminatory pricing rule is that it can create the possibility of an inefficient allocation of the frequency blocks, where a spectrum block may be sold to one bidder at a price lower than some other bidder is willing to pay for that spectrum block. This can be illustrated by a simple example.

Example 6.3.1:

> Suppose three bidders (A, B and C) are placing bids on FDD1. At a going price of SEK 200,000 bidder A decides to keep his bid on FDD1 and not accept a higher going price. This means that bidder A will lose eligibility but his bid on FDD1 at SEK 200,000 is still binding and may be reactivated at a later stage.
>
> Now, suppose bidders B and C keep placing bids on FDD1 until the going price has reached SEK 250,000. Assume all price increments are SEK 10,000 in this example, so the going price will have reached SEK 250,000 after 5 bidding rounds. At this going price both bidder B and bidder C place a bid at the going price, and bidder B's bid (for example) is selected as the standing high bid on FDD1. In the following bidding round the going price is raised to SEK 260,000 and both bidders decide to

switch to say FDD2. This mean that bidder A's bid at SEK 200,000 is reactivated and is now the standing high bid on FDD1.

Bidder D who has never placed a bid on FDD1 is allowed to switch into FDD1 at the going price of SEK 210,000 and he chooses to do so. Bidders B and C, on the other hand, are faced with a going price of SEK 260,000 for FDD1, a price which none of those bidders are willing to pay.

If the auction concludes with this allocation, bidder D is awarded FDD1 at a price of SEK 210,000 while bidders B and C would be willing to pay more for FDD1 (they have both previously bid up to SEK 250,000 for FDD1). In this example, FDD1 does not go to the bidder who is willing to pay the highest price for FDD1, i.e. the allocation is inefficient.

This example does not imply that we should prefer the uniform pricing rule. The example merely highlights a trade-off. The drawbacks of the uniform pricing rule can also be illustrated by a simple example:

Example 6.3.2:

Suppose bidder A currently has the standing high bid on FDD1 and the auction is near conclusion. Bidder A might suspect there is a gap between his standing high bid on FDD1 and the second highest bid on FDD1. For example, Bidder A might have a standing high bid of SEK 250,000 on FDD1 while the second highest bid on FDD1 is SEK 230,000.

If such a gap does exist, bidder A will see a lower going price for FDD1 if he switched to say FDD2. Bidder A can then switch back to FDD1 by placing a bid at the going price of SEK 240,000 (if we again assume a SEK 10,000 price increment). In this example, bidder A will have lowered the price he pays for FDD1 from SEK 250,000 to SEK 240,000.

However, such a strategy does involve a risk for bidder A. While bidder A knows he has the standing high bid on FDD1, he does not know if a gap exists between his bid and the second highest bid. Bidder A's standing high bid may be tied with the second highest bid (in this case bidder A's bid was selected as standing high bid by random draw). Moreover, bidder A cannot be sure that, if he is successful in lowering the standing high bid, another bidder will not rejoin him in bidding for FDD1.

Suppose bidder A's bid is tied with the second highest bid on FDD1 at SEK 250,000 and bidder A switches his bid from FDD1 to say FDD2. The bidder who was tied with bidder A on FDD1 will now have the standing high bid on FDD1 at SEK 250,000. Bidder A will face a going price of SEK 260,000 for FDD1 if he wants to switch back to FDD1. In this case bidder A's strategy of 'testing the gap' below his standing high bid will have increased the price he pays for FDD1 from SEK 250,000 to SEK

260,000.[7] To sum up, the strategy of switching back and forth involves a risk for the bidder who is using the strategy, as the price may increase or decrease.

A final motivation for using a discriminatory pricing is that the uniform pricing rule may lead to indefinite switching back and forth, as explained in the following simple example:

Example 6.3.3:

Suppose bidder A has discovered that no other bidder is bidding on FDD1 and FDD2 at a price of SEK 200,000. Every time bidder A places a bid for either FDD1 or FDD2 he is selected as the standing high bidder at the price of SEK 200,000. With a uniform pricing rule this means that bidder A can switch between FDD1 and FDD2 indefinitely without losing eligibility and without committing to a higher price. Essentially Bidder A is just stalling the auction.

6.4. Increasing Standing High Bids

The rules on placing bids we outlined in Section 5.5 above states that a standing high bid can only be switched to a different spectrum block, or kept at the same level. A bidder with a standing high bid cannot place a bid at the going price for the spectrum block.

An alternative is to allow a standing high bidder to place a bid at the going price, i.e. increasing the bid without being outbid. The reason why one might prefer this alternative option is that bidders should be allowed to place a bid at the going price if the going price is near the bidder's valuation. Without this option, the bidder will effectively only be able to place a bid at every other going price.

We understand PTS has a preference for this option, and that it has been used successfully before (in the 2.6 GHz auction). However, when the standing high bid can be increased without being outbid, we allow bidders to unilaterally increase the price of specific spectrum blocks. For example, a bidder who is not interested in FDD1 (but knows his competitor is interested in FDD1) could increase the price of FDD1 in the first 10 bidding rounds by successively increasing the standing high bid on FDD1. If another bidder switches into FDD1, he will have to place a bid at the inflated going price of FDD1. The bidder who inflated the price of FDD1 could then switch away from FDD1 and start bidding on the spectrum block he is really interested in. The effect of this bidding behaviour is that the price of FDD1 has been inflated without real competition for FDD1. On the other hand, if the standing high bid cannot be increased, the price of FDD1 can only be increased by competing bids from two or more bidders. We believe this latter case is more desirable if the objective is price revelation that reflects true preferences.

A similar argument can be used against allowing bidders to select from a menu of bid increments (going prices). Again, the main argument for allowing this is that a bidder should be allowed to place a bid which is close to his valuation. On the other hand, a bidder might also use the option to inflate the price of spectrum blocks he is not interested in.

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[7] A secondary effect of Bidder A's temporary switch from FDD1 to FDD2 is that it may trigger competition for FDD2. In case bidder B had the standing high bid on FDD2, bidder A's switch to FDD2 may induce bidder B to increase his bid for FDD2 (not knowing that bidder A will switch back to FDD1 again). This will increase the final price for FDD2.

In both cases (increasing standing high bids and allowing multiple bid increments), the main argument is that a bidder should be able to place a bid near his valuation. This argument applies to going prices that are near the bidder's valuation only. For lower going prices, it is hard to come up with a case for allowing bidders to increase their own winning bids. The trouble is that the auctioneer cannot know when a bidder is placing bids near his valuation and when the bidder is simply inflating the price of a spectrum block.

In summary, there is a trade-off between price revelation properties (not allowing standing high bids to be increased and not allowing multiple bid increments) and the ability to place bids at finer intervals near the valuation of a bidder. We believe this trade-off is best addressed by setting smaller bid increments and maintaining good price revelation properties of the auction. In other words, we recommend that standing high bids cannot be increased and bidders should not be able to choose the size of the bid increment.

6.5. Information to Bidders

The rules on information to bidders we outlined in Section 5.9 above states that bidders will only receive information about going prices, standing high bids and an imperfect measure of progress of the auction. This is a minimalist approach to providing information to bidders.

Since one of the key objectives of the auction is to facilitate an efficient allocation of the six spectrum blocks, the question is: How could additional information to bidders improve the efficiency properties of the auction? We believe that the essential information is contained in the going prices. In each round, bidders will be presented with a menu of going prices, one for each spectrum block, and the bidders can place a bid on any two spectrum blocks they prefer at the current price level.

Reasons for deviating from this minimalist approach to providing information to bidders include cases where valuations of particular spectrum blocks depend on the allocation of other spectrum blocks. For example, if the valuation of FDD1 depends on whether FDD2 and FDD3 are awarded to two bidders, or to one bidder (as a package of two spectrum blocks), information on standing high bids and new bids might be useful to a bidder who is contemplating placing a bid on FDD1. However, we believe no such cases can be made for the 800 MHz award.

7. Implementation Issues

This section assesses whether auction software is needed to implement the SMRA+S format we have recommended in this report. It is our opinion that auction software would be needed for any of the multiple round auction formats we have discussed in this report. The main reasons for recommending auction software include:

§ Auction software allows bidders to place bids from their own premises. This is especially convenient when an auction is expected to span several days, possibly weeks.

§ Auction software provides an easy way to enforce submission of valid bids. For example, the spectrum cap can be enforced in the bidder interface, such that only bids that conform to the auction rules can be placed. In auctions where bids are submitted manually (e.g. on paper), the auctioneer faces the problem of how to handle invalid bids. For example, if a bidder is trying to place a bid on three spectrum blocks, should such an invalid bid be rejected completely, or should it be modified to a bid on two spectrum blocks? These issues can be avoided when auction software is used.

§ Auction software facilitates the creation of a log file that contains details of all communication (messages and bidding) between the auctioneer and bidders. Such a log file can prove to be invaluable in case the auction result is contested by (losing) bidders. The log file contains a complete audit trail and facilitates a reconstruction of all bidding rounds if necessary.

In addition to the administrative benefits of using auction software listed above, some auction formats imply that auction software is necessary for computational reasons. For example, in combinatorial auctions where there are thousands of possible packages of spectrum blocks, the winner determination problem can hardly be solved without the use of computers and specialized optimization software.

For the SMRA+S format, there are no such computational issues, and the auction software could be describes as 'bid tracking software' since the main purpose of the software is to keep track of prices, standing high bids, and the bidder specific information that is provided to each bidder. As a result, we don't foresee any severe obstacles in software development for an SMRA+S auction.

For the specific auction rules we have recommended in this report, our estimate is that implementation costs will be medium. Relative to a simple SMRA auction, the level of detail in the SMRA+S rules does imply that a substantial amount of software testing is necessary. Also, features such as allowing standing high bidders to increase the bid, and allowing bidders to select from a menu of multiple increments, does involve some additional customization and testing.

NERA
Economic Consulting

NERA Economic Consulting
15 Stratford Place
London W1C 1BE
United Kingdom
Tel: +44 20 7659 8500
Fax: +44 20 7659 8501
www.nera.com