Options for the design of the auction in the 700, 1500 and 2100 MHz bands

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Executive Summary

This report suggests auction formats that would be suitable for the forthcoming award of frequencies in the 700 MHz, 1500 MHz and 2100 MHz bands in Austria:

- In the 2100 MHz band 2x60 MHz of paired spectrum will become available when the current licences expire at the end of 2020.
- In the 700 MHz band, 2x30 MHz will become available as the second tranche of digital dividend spectrum; although some of this spectrum is subject to usage rights that will expire only in 2022 (or even later), efforts are underway to clear the entire band for mobile use by 2020.
- In the 1500 MHz band up to 90 MHz in the core band and the extension bands are available for SDL use.

The aim is to include all these bands in a single award process (even though it may be necessary to split the proee in a number of separate stages to manage the complexity of the process). However, the award of the 2100 MHz spectrum must be completed well in advance of the expiry of existing licences in order to provide certainty over the future assignment of the band. Therefore, if the 700 MHz spectrum cannot be cleared in time for an inclusion in a single award process, there would have to be a separate award of the 2100 MHz band, followed by the assignment of the 700 MHz band at a later date. Reflecting the strong complementarity between the SDL spectrum and paired spectrum below 1 GHz, the award of 1500 MHz spectrum should be combined with the award of the 700 MHz band.

In making our suggestions, we are guided by the TKK's objectives for the award, which are (in order of priority) to have a process that:

- is robust to legal challenge,
- ensures that frequencies are assigned in a way that guarantees their efficient use;
- promotes or safeguards competition;
- contributes to the improvement of coverage; and
- promotes innovation.

We take as our starting point that:

- the available spectrum will be awarded initially in the form of frequency-generic lots wherever possible, in order to avoid unnecessary fragmentation of assignments; and that
- the spectrum will be offered in small blocks in order to provide maximum flexibility for bidders to assemble the spectrum portfolio that best suits their needs (given the the relative

scarcity of different bands as signalled through prices in the auction process).

We also consider that the objective of promoting better coverage is likely to involve the assignment of one or more special coverage obligations under which operators will be required to roll out services beyond what they would do purely on a commercial basis.

Given their importance for the choice of auction model, we discuss:

- different options for competition safeguards that might be put in place, ranging from simple spectrum caps to more complicated constraints on outcomes; and
- the options for assigning coverage obligations, from tying these obligations to specific spectrum blocks to offering coverage obligations alongside the available spectrum or in a separate stage.

Outcome constraints can provide greater flexibility in the design of measures to promote or safeguard competition than spectrum caps. Allowing for coverage obligations to be offered alongside spectrum, though not necessarily attached to specific blocks, similarly offers more opportunities to pursue ambitious targets while minimising the risk of spectrum potentially remaining unsold. However, both options have implications for the auction model used and for complexity.

Outcome constraints are best implemented in combinatorial auction formats in which the combination of winning bids is determined through a 'winner determination process': maximising bid value subject to a number of constraints makes including additional constraints on outcomes relatively easy.

Combinatorial formats are also required where the ability to take on coverage obligations is linked to the spectrum portfolio a bidder might acquire.

We have reviewed a number of candidate auction formats using assessment criteria that reflect the underlying objectives, noting that the efficiency objective covers a number of aspects. Specifically, the auction format should:

- allow bidders to express their preferences on a level playing field without distortions that might arise from exposure to the risk of winning unwanted subsets of lots in the case of strong underlying synergies (aggregation risk), which may also require that the format supports non-uniform prices;
- support fluid switching across spectrum portfolios in response to price signals and support price and package discovery to remove substitution risks and reduce common value uncertainty (even though the latter may not be a material concern in the case of a small number of bidders with idiosyncratic value differences);
- minimise the risk of lots remaining inefficiently unsold; and

- be strategically simple and as robust as possible against strategic bidding incentives.

Legal certainty is best promoted by a tested format with simple rules that gives bidders full control over their outcome and allows them to bid back rather than face the risk of potentially leaving the auction empty-handed.

Based on these criteria, we find that:

- a combinatorial format such as the Combinatorial Multi-Round Auction (CMRA) or the Combinatorial Clock Auction (CCA) might be needed for efficiency reasons if there are strong underlying synergies within or across bands (in particular in the case where all three bands are offered in a single award), if outcome restrictions were to be used for safeguarding competition, or if coverage obligations were to be offered alongside, but not tied to, the spectrum blocks.
- a simpler format such as the Simultaneous Multi-Round Ascending (SMRA) auction or preferably the the SMRA-clock hybrid would be suitable for a separate award of 2100 MHz spectrum, unless there are substantial synergies across lots, outcome restrictions were needed, or coverage obligations were to be assigned alongside the spectrum blocks.

As both the award of ambitious coverage obligations and the need to protect competition are a significant source of complexity, we also consider the option of splitting the award of multiple bands into separate stages. Under this proposal:

- 700 MHz blocks subject to different special coverage obligations would be offered in a first stage with tight caps that effectively eliminate competition for incremental spectrum (except in the case of new entry) in favour of competition for the different types of coverage; a standard SMRA format or a sealed bid format are likely to be appropriate for this stage
- the award of the 2100 MHz and the 1500 MHz band would follow in a second stage; a CMRA or an SMRA-clock hybrid are likely to be appropriate for this stage;
- a third stage would deal with the assignment of specific frequencies to winners of spectrum; this stage could utilise the sealed bid combinatorial format that has been used in Austria previously for the assignment of specific frequencies; and
- additional coverage obligations could potentially be offered in a fourth stage in exchange for a reduction in the prices that winners pay for spectrum; this stage could again use a standard SMRA format or a sealed bid.

Although this approach would not allow bidders to substitute between 700 MHz and 2100 MHz spectrum, we consider that this flexibility might need to be severely limited in practice, in order to safeguard competition. Therefore, we believe that this multi-stage approach is well aligned with the award objectives.

1 Introduction and background

RTR is preparing the assignment of spectrum in the 700 MHz, 1500 MHz and 2100 MHz bands and has commissioned DotEcon to advise on potential auction models for this award.

Available spectrum

Specifically, the following spectrum will be available for assignment.

In the **700 MHz band**, there will be **2x30 MHz**. All of the frequencies in this band (the second tranche of the digital dividend) are very similar in terms of their propagation characteristics and any usage restrictions that may need to be imposed to control interference and can therefore initially be offered in the form of frequency-generic spectrum lots. The spectrum is particularly well suited for providing a coverage layer for 4G and 5G services (both in terms of indoor coverage and rural coverage). The band is intended to be available from 2020 onwards, through there are existing usage rights for broadcasting that run until 2022 (and possibly later). We understand that efforts are underway to clear the band for assignment from 2020 onwards but that availability from this time onwards is not guaranteed at the moment.

(Up to) **90 MHz** are available in the **1500 MHz band**. The spectrum in this band is harmonised for SDL use and is available immediately. However, a distinction can be drawn between the 40 MHz in the centre of the band (the core band) and the 25 MHz on either side (the extension bands), given that at present only the core band is standardised and supported by equipment vendors. Standardisation for the extension bands is underway, but the extent to which these bands can be used and the timing of the band becoming usable are uncertain. In addition, a further distinction can be drawn with respect to the lowest frequency block, as this block is likely to be of very limited use given the constraints that will need to be imposed to manage interference. Given these differences, it may not be appropriate to offer all of the spectrum in this band as frequency-generic blocks in a single category. However, frequencies within the core band and within the upper and lower extension bands respectively could be offered on a frequency-generic basis (subject to usage restrictions on the lowest block being addressed). If differences between the core and the extension bands were to be regarded as moderate and only the usage restrictions on the lower block were material, another option might be to offer 80 MHz of spectrum in a single category. We understand that operators envisage using these frequencies for TDD applications, but that this is unlikely to be possible given that the band is harmonised for SDL use.

Finally, there will be **2x60 MHz** in the **2100 MHz band**. These frequencies are currently used for 3G and 4G services but are expected to be support 5G in the future. The spectrum will be available from 2021, when current licences expire (at the end of 2020). There are no material differences across different frequency blocks in the band in terms of usability, and therefore all blocks in this band can be offered initially as frequency-generic lots.

TKK's objectives

In considering the different options available for this award, we have been guided by TKK's objectives for this award, which are (in order of priority) as listed below.

Legal certainty: the award process should be robust to legal challenges, ensuring the timely utilisation of the second tranche of digital dividend spectrum. This requires an award design that reduces uncertainty for bidders and offers them the greatest possible control over outcomes (in particular avoiding the risk of leaving the auction empty-handed without explicitly accepting such an outcome). Complexity needs to be kept to a minimum, auction rules should be simple to understand and developing a suitable bid strategy should not be challenging.

Efficient frequency utilisation: This means that the spectrum should be assigned in a way that creates the greatest value for customers and the economy. In line with this objective:

- where bidders deploy similar services, spectrum should be assigned to those users in a way that maximises the overall value, which implies that bidders should be able to express their preferences for different portfolios (including potential synergies within portfolios) on a level playing field;
- spectrum should not remain unused if there are potential users who can create value, and thus, the risk of unsold spectrum should be minimised;
- fragmentation of frequency assignments within bands should be avoided;
- service continuity should not be jeopardised; and
- if winners of spectrum currently hold frequencies in a band and they should have the opportunity to express preferences for retaining specific frequencies in order to minimise re-tuning costs.

This requires that the auction model provides flexibility for bidders to assemble the spectrum portfolio that best meets their needs in response to price signals that reflect conflicting demands. Given the potential differences in requirements across potential bidders, providing this flexibility will typically require offering the spectrum in small blocks combined with an auction design that supports fluid switching between spectrum portfolios, defined as combinations of these spectrum blocks. At the same time, where appreciable substitution or aggregation risks exist, exposure of bidders to these risks should be minimised.

Promoting or safeguarding competition: The outcome of the spectrum award should support effective competition in the downstream markets, which requires that spectrum holdings should not become too asymmetric or concentrated, and that all operators have sufficient resources across all of the relevant bands to be able to compete effectively for customers. Ensuring that service continuity is not at risk is again an important issue here. RTR has conducted a market analysis and identified potential competition problems that should be addressed. Whilst achieving this objective might be seen to be primarily an issue of implementing appropriate competition safeguards such as spectrum caps, there is a close relationship with the auction model as some safeguards may not work with particular models, and the safeguards themselves may affect the performance of different models.

Promotion of coverage: Extending coverage of mobile services and ensuring that 5G services will be available in line with the objectives set out in various 5G strategy plans may require that specific coverage obligations are imposed on winners of spectrum. The award process should be capable of dealing with these coverage obligations and potentially help with assigning them in a way that promotes efficiency and competition.

Promoting innovation: This objective is predominantly linked to making available spectrum without delay and offering the opportunity for innovators to obtain frequencies.

For the avoidance of doubt, **revenue maximisation** is explicitly **not** an objective for this award.

Key assumptions

In considering the suitability of different auction models, we will take the following as given:

- In order to avoid unnecessary fragmentation of bands, spectrum will be offered initially in the form of **frequency-generic lots in a number of categories**. Winners of bandwidth will then be assigned specific frequencies in a second step, in which the priority will be to avoid unnecessary fragmentation of assignments. We consider that this frequency assignment stage could take the form of a single-round sealed-bid process using a second-price rule, which has been used successfully in past awards in Austria. Such a format gives bidders the opportunity to bid on their preferred frequencies without paying more than opportunity costs, which may be negligible if preferences are mutually consistent (as could be the case, for example, were such preferences are determined by trying to maximise the overlap between new spectrum assignments and existing frequency holdings). Should there be objections to the use of a second-price rule, it would be straightforward to use a first-price, pay-as-bid format instead.
- The size of spectrum blocks will be set with a view to maximise the flexibility of bidders to assemble portfolios, unless there are concerns that this might cause an undue increase in complexity or there are other reasons that would suggest that larger blocks be offered. This means that our starting position is

that FDD spectrum will be offered in the form of **2x5 MHz blocks**, and SDL spectrum as **10 MHz blocks** (or **5 MHz blocks** if the amount of spectrum available in a category is not a multiple of 10 MHz**)**.

- Our assessment of competition safeguards should not be limited to **spectrum caps** alone, but also consider whether **other outcome constraints** (such as spectrum floors, restrictions on the maximum acceptable concentration of spectrum, etc.) might be appropriate.
- In terms of participation, we assume that **the three established mobile operators will take part in the award**. Although new entry may be unlikely, the award design should however provide the opportunity for new entrants and non-traditional spectrum users to express their demand for the frequencies on offer.
- The coverage objective will manifest itself in the definition of **one or more specific coverage obligations**, which could be tied to one or more particular spectrum blocks or could be offered flexibly alongside the spectrum.
- Bidders' valuations for the different bands are interrelated, and specifically that (a) the 700 MHz and the 2100 MHz band are considered to be substitutable and (b) that the 700 MHz band and the 1500 MHz band are somewhat complementary, in particular for H3A (owing to the fact that the SDL spectrum can only be used in combination with FDD spectrum below 1 GHz where H3A currently holds only a single 2x5 MHz block).
- For this reason, it would be desirable to **combine the assignment of all three bands into a single award**, unless the late availability of 700 MHz spectrum in combination with the need to assign the 2100 MHz spectrum rules out such an option. It would also be desirable to allow bidders to make bids across portfolios including spectrum in all the bands, unless this were to result in a very complex design. In this case, it might be necessary to split up the award into separate stages, each containing one or two of the available bands.[1]
- If separation of the award were necessary for timing reasons, we assume that there would be a separate award of 2100 MHz spectrum, followed by a combined award of 700 MHz and 1500 MHz spectrum as and when the 700 MHz band becomes available.
- If it were necessary to split up the award into separate stages, we assume that it is desirable that bidders gain certainty over the assignment of the 700 MHz spectrum before they bid for frequencies in the 1500 MHz band.

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[1] In this regard we note, however, that separating the awards may actually increase complexity even if the rules of the individual auctions become somewhat simpler, as bidders will need to deal with the fact that with separate awards switching between the bands becomes impossible and aggregation risks cannot be managed.

- As a matter of course, the auction design will need to comply with any constraints that might arise out of the revised legal frameworks, where we understand that amendments to the telecommunications law (TKG) recently became effective.

Structure of the report

The remainder of this report is structured as follows:

- In Section 2 we briefly discuss the linkages between the auction format and the of different types of competition safeguards that might be used and the way in which coverage obligations might be assigned.
- In Section 3 we provide a brief overview of the candidate auction models considered for this award.
- In Section 4 we summarise our views and suggest appropriate models for the different and coverage obligations for the various options that might be used for the award (in terms of whether the bands will be offered simultaneously or sequentially, and what form competition safeguards and coverage obligations might take).

2 Competition safeguards and the assignment of coverage obligations

2.1 Options for safeguarding competition

Safeguarding competition is an essential objective for this award, and competition safeguards will be defined so that potential concerns are being addressed. Of relevance for the auction design are:

- measures to address concerns the risk of foreclosing competition through the acquisition of spectrum; and
- potential concerns about wholesale provision once the current MVNO obligations expire, which might be addressed through an MVNO obligation, potentially linked to particular spectrum blocks to be assigned as part of the award.

Spectrum caps

Measures to prevent excessive concentration of spectrum holdings (either in a specific band or part of the spectrum, or overall) that might foreclose or distort competition can take a number of forms. Most commonly used are spectrum caps that limit bandwidth that an individual bidder can acquire in the auction. Such caps could be set for specific bands or across a number of bands. They can take account of existing holdings, potentially aiming to reduce any asymmetries that exist prior to the award. Such caps will constrain different bidders to a different extent.

Spectrum caps can also be layered, i.e. various caps can be combined. If spectrum caps are set so tight that the amount of bandwidth that a subset of bidders can acquire is less than the available supply, they create implicit reservations.

Spectrum reservations

Setting caps on the amount of spectrum that individual bidders can acquire is, however, not the only option. Competition safeguards might also take the form of (specific or flexible) spectrum reservations, joint caps (which are more likely to create implicit reservations), spectrum floors or other constraints on the possible outcomes of the award process (such as limits on some measure of concentration).

Spectrum reservations set aside some spectrum for specific bidders (typically potential or recent entrants) so that such bidders are shielded from competition from other bidders who are not allowed to bid on the set-aside spectrum (typically incumbent or well-established operators).

The simplest way to implement a reservation is to identify specific lots as being reserved – this approach is feasible across all auction formats, even those where the winning bid for each lot is established independently, such as the SMRA.

Where multiple bands are on offer, the downside of this approach is that it does not allow bidders who are eligible to bid on the set-aside spectrum to express any preference they might have over the specific bands in which they would prefer the reservation. This could be addressed through flexible reservations, for instance, where some minimum bandwidth is reserved but without specifying in which band.[2] A more complex arrangement would be to allow bidders who are eligible for the reservation to 'opt-in' to a range of alternative spectrum portfolios and then constrain outcomes to ensure that one (or more) of such bidders(s) win(s) one of these portfolios; this approach essentially sets a 'spectrum floor' for a number bidders.[3]

Outcome constraints

Unlike individual spectrum caps and simple reservations of specific lots, more flexible approaches will typically require using outcome constraints, which do not directly restrict the bids that bidders can place, but rather impose limitations on the acceptable outcomes of the award process. As a result, these more flexible approaches may only be viable where winning bids are determined jointly on all lots at the same time.

Outcome constraints would be aimed directly at ensuring that minimum number of operators will have sufficient spectrum after the award to be 'viable' operators in the market or could also be used to impose limits on other concentration measures, in order to rule out outcomes in which spectrum holdings are too asymmetric.

However, while outcome constraints are more flexible and can avoid inefficiencies associated with simple reservations, they come with their own challenges. One concern is that such constraints may be leveraged. For example, a bidder who is guaranteed to win one portfolio from a range of portfolios may try to get additional spectrum at little additional cost by bidding only on packages that are strictly greater than the guaranteed portfolios. In order to prevent such strategic leverage, it may be necessary to introduce requirement to place bids on smaller portfolios that are just sufficient to meet the floor conditions (as, for example, in the UK 4G auction), which could create aggregation risks for such bidders and can make bidding decisions more complicated.

[2] This approach was used in the Netherlands, where entrants were reserved 2x10 MHz below 1 GHz, but this could be in the 800 MHz band or the 900 MHz band. In this case, the flexible reservation was equivalent to setting a joint cap on incumbent operators across the two bands.

[3] This approach was used in the UK 4G auction, where eligible bidders could opt in to ensure they could end the auction with a minimum portfolio, taking into account existing holdings. For instance, Hutchison 3G UK was allowed to opt-in for winning either of 2x5 MHz of 800 MHz spectrum or 2x20 MHz of 2.6 GHz spectrum, which it did. In the end Hutchison 3G UK won 2x5 MHz of 800 MHz.

It may also be that, for a given set of bids, there are no feasible outcomes that comply with the set of constraints. It may therefore be necessary to establish a ranking of constraints and fall-back to lower-ranked ones if no feasible outcome exists under the more highly ranked constraints[4].

Limitations arising from the use of different competition safeguards

All competition safeguards constrain outcome – whether implicitly or explicitly – and can in the extreme practically predetermine the results of the bidding process: If there is little flexibility for bidders to acquire different bandwidths/portfolios, the role of competition for incremental spectrum in terms of finding the efficient assignment is very limited.

Spectrum caps are a relatively blunt instrument. In order to provide effective protection of weaker competitors, they might need to be set so tight that very little scope for competition remains. However, they are easy to implement and understand.

Joint caps, which limit the amount of spectrum that a group of bidders is permitted to acquire at most, are somewhat more flexible and create implicit reservations for bidders but may not work with all auction formats (e.g. they would be difficult to implement in an SMRA). Spectrum floors and other outcome constraints retain more flexibility but come at the cost of greater complexity.

There is a clear interrelation between the choice of competition safeguards and the choice of auction model, as some constraints cannot be implemented (or not be implemented easily) with an auction format that does not feature a winner determination process in which winning bids are determined jointly across all lots. Therefore, the implications for the choice of auction model have to be taken into consideration when determining the appropriate form of competition safeguards. For example, the SMRA format, which involves evaluation of bids on a per-lot basis (i.e. a standing high bid is determined for each lot individually), works well with spectrum caps or simple reservations of specific lots, as these limit the bids that individual bidders can place. However, the SMRA would not be able to include outcome constraints that impose limitations on admissible combinations of winning bids without an unreasonably high risk that lots would go unsold or an outcome would be infeasible. If such constraints were considered to be needed, the implication would be that this auction format could not be used.

[4] Alternatively, one could define an objective function that takes into account concentration or other measures on which outcome constraints could be based. For instance, one could set a value to a constraint being met, in which case the constraint might be dropped if an outcome under the constraint is infeasible, or if imposing the constraint implies a loss in the value of winning bids that exceeds the value specified for the constraint being met. More generally, it might be possible to trade-off such measures against the value of bids. However, the difficulty under this approach is establishing the value for such measures, or for the constraint being met, in a way that reliably reflects the objectives.

Last but not least, competition safeguards may also take the form of assigning particular obligations, such as a requirement to provide access to MVNOs or national roaming, as part of the award. In terms of picking the appropriate auction model, the issues arising in relation to the assignment of such obligations are very similar to how coverage obligations might be assigned, which we will discuss next.

2.2 Assignment of coverage obligations

Improving coverage is one of the main award objectives. In line with the 5G Strategy for Austria (following the European Commission's 5G Action plan), next generation services should be available on all main traffic routes by the end of 2023 and by the end of 2025 5G services should have reached near complete area coverage. This is likely to require coverage obligations that are ambitious yet economically feasible, and ways of assigning them to operators that do not jeopardise the other award objectives (e.g. do not create a risk of unsold spectrum).

Current plans are to have targets for covering households not having access to broadband, and to have some obligations to cover main traffic routes and area coverage targets. Whilst it may be desirable that some of these targets are met by all operators, others could involve providing services that would not, on their own, be commercially attractive or viable. In order to minimise the cost of delivering such obligations, it may be desirable that only one operator is required to meet the targets and that the operator who can do so at the lowest cost is selected. On the other hand, to the extent that serving the coverage obligation could create competitive advantages for the designated operator in the long term, it may be desirable to promote sharing of the overall obligation amongst operators, e.g. on a geographic basis, with different operators providing extra coverage in different regions.

Defining the scope of coverage obligations

A general challenge when defining coverage targets in is to ensure that the cost of meeting them is not prohibitive. Setting very onerous coverage targets risks that they – and any spectrum to which they might be tied – may remain unassigned.

An alternative to pre-defining a coverage target is to let the bidding process itself decide how much additional coverage will be provided. This makes the level of additional coverage achieved ultimately dependent on offers from bidders. The advantage of this approach is that the risk of choking off demand by setting an excessive obligation is greatly reduced. On the downside, the level of additional coverage may fall short of expectations.

Coverage obligation assigned to specific lots

One common approach for allocating coverage obligations through an auction process – used for example in the Austrian 4G auction as well as the 4G auctions in the UK and in Slovenia – is to tie the requirement of meeting the coverage targets to a particular lot. This lot may be larger than other spectrum lots in the band and can sell at a discount reflecting the cost that the winner of the lot will have to incur in meeting the obligation.

The level of the coverage obligation is usually pre-determined. However, this need not be the case. PTS in Sweden, for example, used a relatively simple approach for allowing the level of coverage that had to be provided by the winner of a specific lot to be determined – at least to some extent – through the auction:[5] Up to a threshold value, bids on a particular lot represented a commitment by the winner to invest in improving coverage rather than a payment to the government. Only if bids exceeded this value would the difference between the bid amount and the threshold value count towards auction revenue. Under this approach, the actual level of coverage investments is determined by the auction process. Specifically, the auction process will determine whether the value of spectrum exceeds the cost of the most ambitious target. If bids remain below the threshold level, more moderate coverage levels will be achieved, but there is a lower risk that the spectrum might remain unsold because of overly ambitious coverage obligations with which a winner would have to comply. Such more ambitious targets will only be realised to the extent that the investment costs are covered by the value of the spectrum.

Sharing of the obligation

It is also possible to split the obligation into different components (e.g. a number of obligations for different regions), tie these components to different lots, and thus enable outcomes in which the burden of meeting the coverage obligation is shared amongst different winners. Such a sharing of the obligation may be desirable even if judging on the cost of meeting the obligation alone it would be more efficient if a single operator were tasked with providing all of the required coverage. A somewhat higher cost incurred when the obligation is shared, may be more than outweighed by the benefits from not creating asymmetries that might arise, for example, from market benefits obtained by a single provider of extended coverage.

However, splitting the obligation and linking it to different blocks may preclude outcomes in which a single operator takes on the burden even when this would result in large cost savings that are greater than any benefit from avoiding long-term asymmetries amongst operator. This is because such outcomes would require that a single operator wins all the frequency blocks to which the individual components of the coverage obligation are tied. However, this might not be an efficient assignment of the spectrum (and might even not be permissible under the competition

[5] PTS adopted this approach in its 800 MHz auction (2011) and will also use it in the upcoming 700 MHz auction.

safeguards adopted), in which case there would be a conflict between efficiently assigning the coverage obligation and efficiently assigning spectrum.[6]

Linking coverage obligations to spectrum blocks works well with all auction formats but increases complexity to the extent that special coverage obligation lots would need to form a separate lot category. In addition, further complications might arise when coverage obligation lots have a different bandwidth, as this could create switching impediments or other problems in the simpler auction formats, as we discuss in Section 3.[7]

Default coverage obligation on all lots and exemptions

An alternative approach is to impose a coverage obligation on all spectrum blocks and allow bidders to bid for exemptions, as in the Danish 800 MHz auction.[8] Limiting the supply of exemptions to be one less than the number of winners of spectrum ensures that there will be at least one operator who is assigned spectrum with the coverage obligation. Under this approach it is also possible to split the coverage obligation (e.g. into a number of regional obligations) to allow for the possibility that operators might share the burden. This approach is more flexible than assigning regional obligations to different blocks, as it allows operators to take up multiple obligations without necessarily acquiring more spectrum lots by simply bidding for spectrum without the corresponding exemptions. The auction process would determine whether the coverage obligation will be met by a single winner or shared amongst spectrum winners.

This approach to assigning coverage obligations requires an auction format that allows endogenous adjustments of supply, or a combinatorial auction format that features a process for selecting the combination of binning bids subject to a number of constraints.

Coverage obligations unlinked to spectrum

Yet another approach is to offer spectrum and coverage obligations in the same award procedure, but without specifically linking obligation to the spectrum. Instead, bidders would have the option to bid for coverage lots (which would imply a coverage

[6] For example, if there are six lots of 2x5 MHz available in the 700 MHz band, and a coverage obligation split into three regional obligations each linked to a separate 2x5 MHz lot, then a bidder would only be able to take up the obligation in all regions if it acquired at least three lots, i.e. half of the spectrum available.

[7] For instance, suppose that four 2x5 MHz lots without coverage obligation (A lots) are offered alongside a 2x10 MHz lot subject to the coverage obligation (B lot) in an SMRA with traditional activity rules. If the B lot is given twice the eligibility points given to an A lot, then a bidder who has dropped down to a single A lot will not be able to switch to the B lot (even if the price of an A lot increases beyond the point at which the bidder would prefer the B lot instead); conversely, if the B lot is given the same eligibility points as an A lot, then bidders cannot switch between two A lots (2x10 MHz without the coverage obligation) and the B lot (2x10 MHz with the coverage obligation).

[8] Exemptions would also have been available in the more recent 1800 MHz auction in the case that coverage obligations had not been assigned in the first auction stage.

commitment for the bidders alongside spectrum lots, in exchange for a discount on the amount they would have to pay for the spectrum lots). These coverage lots have effectively a negative price, but otherwise can be treated like spectrum lots. Such an approach is currently considered by UK regulator Ofcom for the forthcoming award of 700 MHz spectrum. Total discounts may be limited to the value of bids for spectrum blocks, or a proportion thereof, in order to avoid outcomes where winners received payments. In order to ensure that coverage obligations are assigned, the selection of winning bids would not only maximise the value of bids (as the assignment of coverage lots reduces bid value) – instead, the value of alternative outcomes would need to reflect the value of assigning coverage lots. Alternatively, there may need to be certain constraints on acceptable outcomes.

The assignment of coverage obligation lots alongside spectrum blocks requires an auction format that supports combinatorial bidding.

Separating the assignment of coverage obligations and spectrum

The need for a combinatorial auction format can be avoided if the assignment of coverage obligations and the assignment of spectrum is separated into distinct stages. Spectrum would be assigned first, and then, in a follow-up stage, bidders would be given an opportunity to bid for taking on coverage obligations in exchange for a reduction in the price they pay for spectrum. Whilst this approach does not require combinatorial bidding, a potential downside is that bidders cannot express any linkage between their ability to provide coverage and the amount of spectrum they win.

A key difference between an auction to assign spectrum and an auction to assign coverage obligations is how to assess bids. In a spectrum auction, bids are typically selected with a view to maximise the total value of financial offers, reflecting the value of assigning the spectrum to bidders. However, the objective when assigning coverage obligations would depend both on the value obtained from improving coverage and the cost of procuring the obligations. Therefore, the objective function to be maximised when selecting bids would need to take into account the social benefits from improved coverage achieved in a particular outcome and its cost.[9]

The separate assignment of coverage obligations provides a more flexible way of determining the level of coverage through a bidding

[9] For instance, the net value of a possible outcome could be calculated as the value (expressed in monetary terms) of the coverage obligations assigned minus the total discount given to bidders who are assigned coverage obligations. The winning outcome would then be that which achieves the highest net value.

process.[10] Depending on the format of a coverage obligation auction, information about cost will be revealed through the bidding process itself. However, in order to achieve the optimal level of additional coverage still requires a very clear indication of the value associated with different incremental coverage targets (and potentially also a reasonable indication of the cost of meeting them).

With coverage obligations being defined in the form of particular areas where services have to be provided (rather than in the form of general population coverage targets), it is relatively easy to let bidders make offers for different targets. As a result, it is easy for bidders to 'share' the coverage obligation, by allowing them to meet the obligation with regard to some, but not all the coverage targets, and the bidding process – at least in principle – can make sure that coverage targets will be met by the bidder(s) with the lowest cost. It will also determine the maximum additional coverage that can be achieved with a given budget, assuming that the bidding process is competitive and well designed to avoid distortions from strategic bidding.

Sequential or simultaneous offer of different coverage targets

Where different coverage targets are offered to bidders, this can be done sequentially or simultaneously.

If offered sequentially, bidders would be invited to compete for a specific target, and the bidder offering to provide the required coverage for the lowest level of compensation would win. Provided that the available budget (i.e. the proportion of auction fees from assigning spectrum that will be used for securing coverage) is not exhausted, bids for the next target would then be sought, and so on, until either all targets have been assigned, or the budget is exhausted. This solution is simple but has some substantive shortcomings:

- if the budget is insufficient for procuring all targets, the sequential approach does not allow for a global optimisation of coverage – i.e. there is no guarantee that the coverage targets that produce the greatest social value net of cost will be selected. Indeed, the order in which targets are offered can

[10] It is of also possible to use a follow-up stage to assign a single coverage obligation to the operator who is best placed to meet it. However, with a single coverage obligation to be assigned, this is equivalent to linking the obligation to a particular lot in the auction, where the effective discount on price should be largely equivalent to the compensation that the eventual winner of the follow-up process would receive. In this case, linking the obligation to a specific lot might be preferable, as it will allow bidders to bid for spectrum already taking into account the potential discount they would enjoy if they take up the coverage obligation.

affect the outcome, and thus the level of coverage and the value from procuring coverage.[11]

- if the costs of providing coverage across different targets were interrelated (e.g. any potential substitution and complementarity effects between targets), then the sequential approach would not provide an opportunity for bidders to choose the targets that each could serve most cost-effectively, or express cost savings from covering multiple targets.

Therefore, offering all of the coverage targets simultaneously is likely to be more efficient for the same reasons that simultaneous awards of spectrum are better for efficiency than sequential ones, but is also more complex mechanically. In terms of selecting an auction format for this process, the choice depends on the scope for substitutability and/or synergies across the different coverage targets. If synergies across different coverage targets are unlikely, then a simple process where bidders can make independent bids for each target might be appropriate, for instance in a sealed-bid process. Such a process would still make it possible to pick the targets that create the greatest net social value (or generate the largest 'cost saving' relative to an initial cost estimate) subject to not exceeding the available budget. Conversely, a combinatorial auction may be more appropriate if there are synergies between different coverage obligations.

[11] In order to optimise the outcome, it might seem reasonable to offer targets in decreasing order based on the value of procuring coverage for that target, so that we first use the available budget on the targets with greatest value. However, the optimal outcome does not only depend on the value of targets for which coverage has been procured, but also on the cost of procuring this level of coverage, which will only be revealed in the course of the bidding process. Therefore, it is possible that a better outcome could have been achieved had targets been offered in a different order.

Example 1: Assigning coverage targets

Consider that there are three coverage areas A, B and C. Assume that the value of providing coverage in these areas is known, and as shown in the table below. Assume further that there are three operators X, Y and Z, who offer to provide coverage in these areas in exchange for compensation as specified. These are the 'bids' made by the operators in the reverse auction.

Area	Value	Offer from X	Offer from Y	Offer from Z
A	100	50	60	60
B	180	140	120	150
C	120	100	90	80

From these bids, it is clear who would be best placed to provide coverage in the various areas, and what the 'net value' of obtaining coverage in these areas would be:

- Letting X provide coverage in Area A produces a surplus of 50, at a cost of 50
- Letting Y provide overage in Area B produces a surplus of 60, at a cost of 120; and
- Letting Z provide coverage in Area C produces a surplus of 40, at a cost of 80.

With an unlimited budget, it would obviously pay to have all three areas covered by the bidder who makes the best offer. However, if the available budget were limited, this may not be possible. For example, if the maximum amount that can be spent on obtaining additional coverage is limited to 100, the it would not be possible to procure more than one target, and the best outcome would be to let X provide coverage of area A.

With a budget of 120, the best option would be to let Y cover B; and

With a budget of 130 (or more, but below 190), the best outcome would be to let X cover A and Z cover C.

3 Assessment of candidate auction formats

3.1 Assessment criteria

Our assessment criteria capture the award objectives set out above.

Legal certainty requires simplicity, transparency and providing each bidder with the opportunity to retain control over its auction results

In relation to the objective of **ensuring legal certainty**, it is important that the auction process is **simple and transparent**. Complex rules that are difficult for bidders to understand increase the risk of bidding mistakes and subsequent challenges. Transparency in this context means that the way in which bid decisions translate into results needs to be easy to understand, so that bidders can follow the process without problems.[12] Bidders should be able to **retain control over their own auction results** and not be exposed to unnecessary uncertainty over outcomes. In particular, a bidder should not face the risk of leaving the auction empty-handed unless it has accepted such an outcome.

Efficiency objective has multiple facets

The efficiency objective requires that the auction design allows bidders to express their preferences for different spectrum portfolios (in combination with coverage obligations, as appropriate) on a level playing field and without being exposed to the risk of winning unwanted combinations of spectrum lots or overpaying for the lots they win. This requirement has multiple implications, which we consider in turn.

Efficiency: dealing with aggregation risks

This is of particular relevance in relation to aggregation risks that arise from complementarities between lots in the underlying valuations. Lots are complementary when the overall value a bidder places on their combination is higher than the sum of the standalone values it places on each lot individually. Complementarities arise naturally because of spectral efficiency gains from deploying wider carriers with spread spectrum technologies; for example, a bidder might be willing to pay for 2x10 MHz significantly more than twice the amount it would pay for 2x5 MHz on its own.

Complementarities may also arise from the fact that bidders want to acquire contiguous frequencies or larger bandwidths in a single band rather than split across multiple bands. Even in the case where bidders have a business case for spectrum exhibiting decreasing marginal valuations for additional spectrum (i.e. the first block is worth more than the second, which is worth more than the third and so on), there may be complementarities because having all the

[12] For the avoidance of doubt, this is not about the appropriate information policy. Transparency in this context does not require that all bid decisions are laid open at all times.

spectrum in one band may be preferable to having split holdings. For example, a bidder may consider 2x10 MHz in the 2100 MHz band to be a good substitute for 2x10 MHz in the 700 MHz band, but may not be particularly interested in having only 2x5 MHz in each band. If the spectrum is offered in 2x5 MHz blocks, such bidder might be interested in winning two lots in one band or two lots in the other band but would wish to avoid a split outcome.

Complementarity exposes bidders to so-called aggregation risks: the risk of ending up with an unwanted combination of lots or overpaying for a subset of the target portfolio, having made bids in the expectation of being able to win the full complement but failing to do so.

Aggregation risks are eliminated in auction formats that support package bidding, where bids for combinations of lots are assessed in their entirety. As a result, bidders are never exposed to the risk of winning an unwanted subset of lots. In other auction designs that evaluate bids on a lot-by-lot basis, these risks can be mitigated by mechanisms that allow bidders to withdraw provisionally winning bids. However, such withdrawal opportunities can create problems as bids cease to be committing, and therefore withdrawals may need to be limited or penalised or triggered automatically (as in the case where bidder can specify a minimum requirement of lots, with any provisionally winning bids for a lower quantity becoming void when the bidder fails to win at least the pre-specified quantity).[13]

Efficiency: dealing with substitution risks

Lots are substitutes when a bidder might be willing to acquire one or the other (i.e. switch their demand across the lots), depending on their relative price. In the extreme case lots may be perfect substitutes (i.e. a bidder would prefer whichever lot is the cheapest by even an infinitesimally small amount), but in general, substitutability is imperfect, i.e. bidders may attribute different values to different lots, and thus bidders may only want to acquire the lot with lower value if there is a sufficiently large price difference between the two lots.

Efficiency in this case requires that lots are assigned in line with relative valuations (which means that there would be no gains from trade between winners, so that at the final prices each winner prefers the lots it has won to those won by others), and we call *substitution risk* the risk that a bidder might end up winning some lots that are not its preferred lots at final auction prices.

In sealed-bid processes, substitution risks can be mitigated by allowing bidders to reveal their full demand profile, through a sufficiently rich set of bids for alternative combinations of lots, instead of requiring that they select a specific combination of lots or that they bid for individual lot (which could lead to a wide range of combinations of lots depending on which bids become winning

[13] Such provisions were used, for example, in the German 4G auction of 2010 or the recent UK auction of spectrum in the 2.3 and 3.4 GHz band.

bids). In open auction processes, substitution risks can be mitigated with rules that allow fluid switching between combinations of lots in response to price signals; conversely, where there are switching impediments there is a risk that bidders might end up locked with bids on lots that are not their preferred ones at final prices. This issue is closely related to aggregation risks, as often switching impediments arise when bidders would want to switch between combinations of lots rather than individual lots.

Efficiency: dealing with common value uncertainty

To the extent that bidders' valuations are driven by common but uncertain factors, efficient outcomes are more likely in auction processes that help to mitigate such common value uncertainty. This is typically an argument used to support the use of open multi-round processes, potentially with the maximum amount of information about each bidder's bidding behaviour being made available at each point, as being able to observe each other's behaviour could help bidders with updating their own valuations. However, it is unclear how material this issue might be in a situation with a relatively small number of bidders and potentially substantial private value components, as the scope for updating valuations in light of the observed behaviour of other bidders is likely to be limited. In such an environment, the benefits from an open process are more likely to derive from the information that bidders might obtain about the outcomes that are likely to be achievable, and discard targets that are unlikely to be obtainable.

Efficiency: reducing strategic complexity

In order to ensure that we assign the lots efficiently it is important to receive all bids that are relevant for determining this outcome. When there is substitutability, then it is desirable that the bids submitted by bidders reveal information about the relative valuations of different spectrum portfolios across different bidders. Therefore, providing incentives for truthful bidding is therefore the ultimate objective of auction design; however, this is difficult, if not impossible to achieve, except under very limited conditions.

One reason why bids might provide distorted signals of individual valuations is underlying strategic complexity, which is different from the complexity of the auction rules or the auction mechanism. For instance, the rules of a first-price, sealed-bid auction are simple; however, from the point of view of a bidder, determining the right bid level is strategically complex, as it involves establishing by how much the bid should understate the true value to the bidder (bid shading) in order to maximise the expected surplus from winning. Lowering bids increases the surplus if the bidder is successful but reduces the probability of such an outcome. Bidders will typically need to determine their bids not only on the basis of their own valuations for the lots, but also taking account of their expectations about the valuations and the behaviour of other bidders, which could be incorrect. As a result, determining the amount by which bids should be shaded is strategically very complex.

Strategic complexity may also arise when there are many lots on offer if there is a wide range of packages of potential interest for bidders. Under some formats with some sealed-bid elements (e.g. sealed-bid processes, or CCAs), bidders may wish to submit a large set of bids for alternative packages to reduce the risk of leaving the auction empty-handed, with the concomitant uncertainty over the eventual outcome that a bidder will obtain. This is particularly challenging where budget constraints impose limits on the ability of bidders to express their full range of valuations in their bids.

Efficiency: susceptibility to strategic bidding

Another reason for bids not reflecting underlying valuations is that bidders may bid strategically with the objective of manipulating prices or the winning assignments rather than responding to price signals. Such strategic bidding covers a wide range of possible behaviours.

Strategic bidding is mainly, but not exclusively an issue in open auction processes and the risk of strategic bidding is pervasive. This is not least because the typical assumption made in the theoretical auction literature that bidders are driven by surplus maximisation (i.e. trying to maximise the difference between the value of lots won and the price to be paid for them) might not hold in practice, where bidders are often concerned about performance relative to competitors, or may simply pursue alternative portfolios in hierarchical order within their give budget, rather than choosing between them on the basis of maximising surplus.

In broad terms, pay-as-bid auctions (as the SMRA and clock variants, and the CMRA) typically create incentives to understate demand and valuations, in order to keep prices down, whereas opportunity cost-based pricing (generalised Vickrey pricing or minimum revenue core pricing, as in second-price, sealed-bid combinatorial auctions, and in the CCA) can create incentives for overstating demand and valuations for incremental spectrum, in an attempt to drive up competitors' prices (even in a single round sealed-bid setting). Collusion concerns may arise under both pricing regimes in open multi-round processes, if there is scope for signalling and accommodation.

Efficiency: potential inefficiencies arising from uniform pricing when there are strong complementarities

With strong complementarities, there may be no set of uniform per-lot prices that support an efficient outcome. Consider the simple case where a bidder values two blocks at more than double its valuation for a single block – at any price at which such a bidder would be happy to acquire a single block, it would prefer to acquire two blocks, as this provides a greater surplus. If the price per lot rises to the point where the bidder is not interested in acquiring two blocks, then the bidder will also not wish to acquire a single block. Therefore, when the prices per lot reaches this point, the bidder's demand will drop from two blocks to none. However, if excess demand was only one block, then we go from a situation of excess demand to one of insufficient demand, and there are no intermediate prices that would avoid this. The bidder would have been willing to acquire a single lot if this was offered at a discount relative to the price per lot that would apply for a two-lot package.

Notice that in auction formats that evaluate bids for each lot separately (as the SMRA) the bidder might still be assigned a lot when reducing demand from two lots to no lots (e.g. the bidder might have a standing high bid on one lot from previous rounds). However, in this case the bidder may be required to pay a price for its lot that exceeds its valuation (i.e. is exposed to aggregation risks), which might discourage the bidder from bidding on two lots up to their actual valuation. Furthermore, whilst assigning the lot to the bidder at a price that exceeds its valuation might be preferable to leaving the lot unassigned if the bidder places any value on a single lot, there is no guarantee that the bidder may have any interest in a single block at all (for instance if the bandwidth provided by a single lot is insufficient for any viable business case), or that there is no other bidder who would place a higher value on a single lot (in which case it would be more efficient to assign the lot to this other bidder).

This means that auction formats that do not allow to set different prices per lot for different packages may fail to produce an efficient outcome. Such auctions can result in inefficiently unsold lots, or more generally an inefficient assignment, or can create a risk of bidders over-paying (and therefore being discouraged to bid for two blocks up to their value).

Risk of inefficiently unsold lots

Above we have identified different reasons why lots may go inefficiently unsold, including:

- lots might go inefficiently unsold due to substitution risks (i.e. a bidder might have wanted to acquire the lots at its final prices, but ended with different lots or no lots at all due to switching impediments or not having made all of the relevant bids); or
- depending on the auction format, lots might go unsold if demand falls abruptly and we move from a situation of excess demand to one of insufficient demand, and we do not have bids for lots at prevailing prices, despite the fact that some bidders would have been willing to acquire the lots at a lower price.

The risk that lots may go inefficiently unsold may be of particular concern, as unlike in the case that spectrum is assigned to a bidder with a lower valuation, the loss in value might be greater if the spectrum remains unused. For this reason, for each auction format we specifically consider the risk that lots may remain unsold.

Safe-guarding and promoting competition

This objective is achieved primarily by adopting the appropriate competition safeguards and the concern in relation to the choice of auction model is largely about the extent to which a particular design works well with various potential measures.

Promoting coverage

Again, the main lever to achieve this objective is the way in which coverage obligations are defined but auction design matters to the extent that it supports the different options for defining and assigning coverage obligations.

3.2 Overview of candidate auction formats

3.2.1 Sealed-bid auctions

A sealed-bid auction involves bidders submitting their bids without having the opportunity to respond or react to the actions of other bidders – even if different bidders' bids were collected sequentially, each bidder would essentially face a single round of bidding.

Having received these bids, the auctioneer then selects the winning bids and calculates prices. Sealed-bid auctions are very flexible with regard to how both of these decisions are taken. For instance, bids can be evaluated using a combinatorial approach or individually for each lot, and bidders can be required to pay the amount of their bid or a price that is determined by the opportunity cost they impose on other bidders (e.g. pure Vickrey prices, or minimum revenue core prices).

Sealed-bid auctions are easy to implement. However, they do not provide opportunities for bidders to respond to price signals and determining the optimal bid strategy may be very complex for bidders depending on the pricing rule, whether bids are regarded as package bids or bids for individual lots, and the number of lots available.

With complementarities, sealed-bid, combinatorial auctions are a simple way of removing aggregation risks. However, we can only be sure of an efficient outcome if bidders express their (true) preferences over a sufficiently large number of packages so that all combinations of lots that might potentially be relevant in the optimum allocation are included. This can be challenging if the number of packages is large, and bidders have little information about what combinations of lots they might realistically expect to be able to win. An open bidding process, by contrast, might reveal information that may help bidders to narrow down the number of packages they could win, but in a single shot sealed-bid bidders may need to consider a much greater range of outcomes that could arise, and could focus on the wrong packages (especially if there is a limit on the number of bids that each bidder can submit, or if bidders have a limited budget and need to consider which packages they may be able to win within their budget).

The task of expressing a full demand profile can be made easier through appropriate bidding languages. However, these will involve simplifications that limit the extent to which package valuations can reflect synergies. As a result, the benefits from package bidding may be reduced.

Moreover, there are a number of reasons why bidders may not be able or willing to submit bids that reflect their valuation in addition to simply failing to identify all the relevant packages they should consider. For example,

- bidders may be unable to reflect their full valuation in their bids, if they have a limited budget – this problem will not only affect the highest bid that a bidder can make for its preferred package, but also limit the extent to which a bidder can express its relative preferences for alternative packages without reducing its chances to win its preferred package, and may provide incentives for bidders to suppress some bids for less valuable packages;
- bidders may not be able to prepare accurate valuations for all possible packages, in which case they would prefer to bid in line with a hierarchical list of alternative targets, and only switch between targets at key points (e.g. when the price exceeds their budget or given thresholds, or at observed levels of excess demand) – such bid strategies are not available in a sealed-bid format that does not feed back information to bidders; instead, bidders will need to make a list of bids on the basis of their expectations about competitors' demand;
- where a first price rule is used, bidders have incentives to shade down their bids to pay less, and thus maximise their surplus in the event of winning – bidders will shade down bids on the basis of their expectations of competitors' bids, which might be wrong and lead to some bidders shading more than others and losing when it would have been efficient for them to win.

Combinatorial evaluation of bids is not a necessary feature of sealed bid auctions – it is also possible to evaluate bids on per-lot basis and combine this with various pricing rules (e.g. pay-as-bid; pricing for groups of similar lots on the basis of lowest winning/highest losing bid, etc.). This approach works well with a single category of substitutable lots and decreasing marginal valuations for all bidders but creates problems where bidders may pursue alternative portfolios or have synergistic valuations, as by expressing demand for different alternative portfolios they are exposed to the risk of winning too much, and there is always the possibility that a bidder might win only a subset of the lots targeted in any particular portfolio (or lots across different portfolios).

The following table summarises our assessment:

Table 1: Summary assessment of sealed-bid auctions

Simplicity, transparency and bidder control over outcomes	Rules are simple and the process is fairly transparent (provided that bids are disclosed after the auction so that the correct selection of winners and prices can be verified) but bidders have no opportunity to 'come back' and adjust their bid decisions; in order to minimise the risk of leaving empty-handed, they may have to make many bids with no control over which ones may become winning bids.

Aggregation risks	Sealed-bid package auctions remove aggregation risks; without package bidding, aggregation risks are substantial (if there are complementarities).
Substitution risks	In combinatorial sealed-bid auctions bidders are typically allowed to submit bids for alternative packages. In this case, the assignment should reflect value differences provided that bidders make a sufficiently rich set of bids. However, under simpler formats, if there any limitations for bidders to bid for all packages of potential interest, or simply if bidders fail to make all such bids, then there may be significant substitution risks.
Common value uncertainty	No price discovery, so no contribution towards reducing common value uncertainty.
Strategic complexity	First-price auction is very complex. Second-price auction is simple as long as the number of potential packages on which bidders can bid is small and budget constraints to not limit their ability to express the value differences across different combinations of lots.
Susceptibility to strategic bidding	Limited, but potential incentive to submit price-driving bids under a second-pricing rule.
Price uniformity	Depends on pricing rule, different lots and/or packages can sell at different prices.
Risk of unsold lots	Can be substantial if there are substitution risks, which are likely to increase with the number of lots available and the alternative packages of potential interest for bidders.
Competition safeguards	Works with all types of competition safeguards.
Coverage obligations	Works with all models for assigning coverage obligations but including coverage obligations into the bidding for spectrum increases complexity. Can be used for separate assignment of coverage obligations.
Overall assessment	We would not recommend using a sealed-bid process for the assignment of a large number of spectrum lots. However, a sealed-bid process can be appropriate for the assignment of residual lots, the determination of specific frequencies for frequency-generic lots assigned in a previous stage, or for the assignment of coverage obligations in a follow-up process, where concerns about budget constraints are potentially much weaker, and where the range of bids could be much smaller.

3.2.2 Simultaneous Multi-Round Ascending (SMRA)

The key feature of the SMRA is that bids are evaluated on a lot-by-lot basis and that it designates provisional winners (standing high bidders) in each round who would become actual winners if the auction ended.

Bidding process

This makes the bidding process intuitive, as bidders only need to improve their offers in response to being outbid and know at any point what their position would be if the auction were to come to an end. Selecting standing high bids also means that lots that received any bids will be sold.

The bidding process works as follows:

- bids apply to specific lots;
- the auctioneer announces the price for each lot at which bids can be made in a round (which is the reserve price for lots that have not received bids and the highest bid received on the lot plus an increment for lots that have received bids) and bidders specify the lots for which they wish to bid at the prices announced by the auctioneer;
- at the end of the round, the auctioneer selects the highest bid on each lot (with random tie-break amongst bids of equal price), which becomes the 'standing high bid';
- at the end of the round, bidders are informed of the highest bid received on each lot, and of the lots on which they hold the standing high bid; and
- if any bids were received in the round, another round is run; otherwise the auction ends, and the standing high bids become winning bids, with winners required to pay the amount of their bids.

If another round is run, bidders can place bids at the higher price, subject to an activity rule that requires that a bidder may not increase its demand relative to the preceding round. In the simple case where the lots offered are perfect substitutes this rule can simply require that a bidder cannot bid (or hold standing high bids) for more lots than in the preceding round. However, if the lots are imperfect substitutes then each lot is given a number of eligibility points, and demand is calculated as the sum of eligibility points associated with the lots for which the bid has bid or held a standing high bid. Further refinements are possible, such as for instance using an activity requirement of less than 100% to allow bidders to switch between sets of lots with different total eligibility, with the possibility that the activity requirement might be tightened as the auction progresses.

If all of the lots offered in the auction are close substitutes (e.g. lots in different bands), and there is no complementarity between lots, then an SMRA works very well, allowing bidders to revise their bids in response to being outbid. The SMRA works still reasonably well when lots are substitutes but heterogeneous, though in this case the typical eligibility points based activity rule can create switching impediments when value differences between lots are reflected in different eligibility point assignments (see example below). More importantly, however, the notion of provisionally winning/standing high bids that is a key concept of the SMRA can create some problems when lots are not merely substitutes because they:

- limit the ability of bidders to switch across groups of lots; and
- expose bidders to aggregation risks in the case of synergistic valuations – as we show with an example below.

These switching impediments can be partially addressed by allowing for withdrawal of standing high bids. The rationale for withdrawals is to facilitate switching between different groups of lots.[14] However, the use of withdrawals complicates the auction, both in terms of mechanics and because it might allow bidders strategically to use withdrawals to distort the auction process in their favour. To mitigate the risk of such behaviour, withdrawals are usually subject to limitations on the number of occasions on which standing high bids can be withdrawn, or penalties (though this limits the usefulness of withdrawals in the first place), or to conditions that link withdrawals to the placement of new bids. However, even with provisions for withdrawals some switching impediments may remain from the typical activity rules used in SMRAs. These require that demand, aggregated across all lots and expressed in terms of the bidder's activity (using eligibility points as a common measure for aggregating demand across different types of lots), cannot increase as prices go up.

Example 2: Switching impediments under the SMRA activity rule

Suppose that we offer four lots of 2x5 MHz, with one eligibility point each, and one 2x10 MHz lot, which is subject to a coverage obligation, with two eligibility points. A bidder is willing to pay up to:

- 10 for a single 2x5 MHz lot;
- 15 for a 2x10 MHz lot subject to the coverage obligation; and
- 17 for two 2x5 MHz lots.

Suppose that the price for 2x5 MHz lots starts at 5 and the price for the 2x10 MHz at 10. The bidder starts bidding for the two 2x5 MHz lots.

If the bidder a has standing high on a 2x5 MHz lot, then it will only be able to switch to the 2x10 MHz lot if it is allowed to withdraw this standing high bid.

However, there are also some switching impediments that are not related to standing high bids:

Suppose that bidding continues and round prices reach 8 for each of the 2x5 MHz lots and 14 for the 2x10 MHz lot. The bidder switches to a single 2x5 MHz lot. But then in the following rounds suppose that the price of the 2x5 MHz lots continues to increase to 9, 10 and 11, whilst

[14] For instance, suppose that a bidder was interested in either lots A and B, or lots C and D. Suppose that the bidder initially bids on A and B and becomes standing high bidder on A but not B. Suppose that in the following round, prices change and the bidder would prefer C and D. As the bidder holds the standing high bid on A it cannot simply switch to bidding for C and D. If withdrawal of standing high bids is allowed, then the bidder can withdraw its bid on A, in order to be free to bid on C and D.

> the price for the 2x10 MHz lot remains at 14. The bidder would then prefer to bid for the 2x10 MHz lot, but this is not possible under the typical activity rules: having contracted demand, the bidder is not allowed to make bids for lots worth more than one eligibility point.

It might be possible to adopt a more relaxed activity requirement (of less than 100%) to facilitate switching between lots with different eligibility. However, this too is only a partial solution that may have its own downsides, such as allowing bidders to withhold or misrepresent their demand until late in the auction.

Aggregation risks in an SMRA

Standing high bids expose bidders to aggregation risks as bidder might hold provisionally winning bids on some lots at the point where they cannot longer afford to keep bidding on others. If the auction ends without being outbid on those lots, the bidder will end up with a subset of lots whose value could be substantially below the level of bids, as these have been made in the expectation of being able to acquire complementary lots. This in turn will affect bidding incentives, as a simple example shows.

Example 3: Aggregation risks in an SMRA

Consider the case of two bidders with the following valuations competing for three lots:

	Bidder A	Bidder B
One lot	11	4
Two lots	20	16

Marginal valuations are decreasing for Bidder A, i.e. the second lot is worth less than the first (9 for a second lot compared with 11 for the first lot). By contrast, Bidder B's marginal valuations are increasing (12 for a second lot compared with 4 for the first lot). If we assign two lots to Bidder A and one lot to Bidder B, we obtain a total value of 24; conversely, if we assign one lot to Bidder A and two lots to Bidder B, we obtain a total value of 27. Therefore, the efficient assignment is to give one lot to Bidder A and two to Bidder B.

In an SMRA Bidder B is exposed to aggregation risk:

- If it bids on two lots beyond a price of 4 per lot, it faces the prospect of ending up winning a single lot and having to pay a price that exceeds its valuation for the lot. For example, suppose that bids reach 8 per lot. At that point both bidders could still pursue two lots. However, Bidder A would continue to bid for two lots when prices are 9 per lot. If Bidder B only stops bidding for a second lot when prices reach 9 per lot, then it will end up with a single standing high bid of 8, which exceeds its valuation for a single lot. Alternatively, Bidder B might continue to bid for two lots in the hope of winning two lots for 18, which would also exceed its valuation but would imply a smaller loss than when winning a single lot for 8. The auction revenue in this case would be between 24 and 27, but Bidder B would be at a loss.
- Bidder B could stop bidding for a second lot as soon as prices are 4 per lot. This would ensure that the bidder is not exposed to the risk of overpaying for a single lot. However, the result would be unsatisfactory for Bidder B, as at this price it would much prefer to acquire two lots. The auction revenue in this case would be around 12.

In an SMRA, bidders facing aggregation risks are at an inherent disadvantage, which is likely to make them bid more cautiously and might even discourage them from taking part in the auction altogether.

Aggregation risks in the SMRA cannot be easily fixed. Allowing bidders to withdraw their standing high bids without penalty or limitation would remove the risk, but at the same time enable them to make bids that they do not intend to honour, possibly to drive up the prices paid by competitors, or to deny spectrum to competitors by making lots too expensive. Bids would cease to be committing, which can create substantial problems.

Another approach that has been taken is to allow bidders to specify a minimum spectrum endowment that they would be willing to accept, so that in the event that they end up standing high bidders on less than this required amount the bidder's bids will be cancelled. However, this rule requires that the bidder must commit to not being able to acquire a single lot before being able to assess the level of competition in the auction.

In any case, removing aggregation risks in the SMRA may lead to some lots going ***inefficiently*** unsold. It is possible that lots may remain unassigned following the cancellation or withdrawal of standing high bids, whilst some bidders might have wanted to acquire such lots at a lower price. However, such bidders may now be unable or unwilling to bid for the lots, as the current price of lots might already exceed their valuation.

On a purely practical level, the SMRA may take a long time to resolve excess demand where a large number of almost identical lots is on offer, as in this case many rounds could be required in order to increase the price of all of these lots by a single increment.

The following table summarises our assessment:

Table 2: Summary assessment of the SMRA

Simplicity, transparency and bidder control over outcomes	Rules are simple, and the process is very transparent. Bidders can come back and raise their bids whenever they are outbid on a particular lot but may be bound by their standing high bids even when they would prefer to be released, unless fairly permissive withdrawal rules are in place.
Aggregation risks	As bids are evaluated per lot, aggregation risks are appreciable whenever there are complementarities between blocks.
Substitution risks	The SMRA allows for switching in response to price differences on a lot-by-lot basis. However, standing high bids create impediments to switching between different packages of lots. Further switching impediments arise as a result of the typical activity rule when lots are heterogeneous and alternative packages of interest have different eligibility (as then switching is only one way). As a result, SMRAs might perform poorly with very heterogeneous lots (unless the activity rules are substantially relaxed), or where bidders wish to substitute between packages rather than between individual lots.
Common value uncertainty	Price discovery should help mitigate common value uncertainty.
Strategic complexity	Bidding is very straightforward for bidders with decreasing marginal valuations and who do not need to consider switching between packages. However, bidders with synergistic valuations need to be careful in order to avoid winning unwanted subsets of lots. In addition, switching impediments may create substitution risks and create a need for bidders to rely strongly on their expectations of final prices.

Susceptibility to strategic bidding	Like any pay-as-bid auction there are incentives for strategic reduction of demand. With bids being placed on individual lots, there is scope for signalling and targeting of particular competitors and thus, which could facilitate collusion (depending on the information policy adopted). Also, depending on switching impediments and activity rules, where different types of lots are available bidders may be able to stage competition to resolve first competition for one type, or drive competitors' prices with the aim of reducing their residual budget for other lots.
Price uniformity	Prices for similar lots will be near-uniform (with differences being limited by the size of the bid increment). Note that, unlike in the case of clock auctions, this will not result in unsold spectrum (owing to the concept of standing high bids). Instead, price uniformity means that winners would be concerned about over-paying for lots (i.e. be fully exposed to aggregation risks) with the resultant implications for efficiency.
Risk of unsold lots	Related to the permissiveness of withdrawal provisions – if withdrawing standing high bids is easy, the risk of unsold lots is substantial. If there are no provisions for withdrawal of standing high bids, or if withdrawals are subject to significant costs, then the risk of lots going unsold when any demand for them has been expressed is small.
Competition safeguards	Works with individual spectrum caps and reservations of specific lots but does not support more complex competition safeguards.
Coverage obligations	Works with coverage obligations being tied to specific lots, or with the assignment of coverage obligations being split out into a separate stage. Can be used for the assignment of coverage obligations in a separate, follow-up stage.
Overall assessment	We would not recommend using the SMRA format if there are substantial complementarities across lot but otherwise the format is suitable for the assignment of spectrum. It could also be used for the assignment of coverage targets. As noted, the format may also not be the most efficient procedure for resolving excess demand where there are multiple almost identical lots.

3.2.3 Clock auction

Clock auctions are well-suited for offering groups of identical items (such as frequency-generic blocks of spectrum).

Description of bidding process

The simple clock auction works as follows:

- identical lots are grouped together into lot categories;

- the auctioneer announces the price for each lot category in a round, and bidders specify the number of lots in each category they wish to acquire at the prices announced by the auctioneer;
- if there is excess demand for any of the lot categories (i.e. if the total number of lots that bidders indicated they wish to acquire at the round price exceeds the number of lots available), then a further round needs to be run, with a higher round price for lot categories that had excess demand; otherwise the auction ends and each bidder is given the lots it specified it wishes to acquire at the round price.

Clock auctions usually use the same activity as the SMRA: lots are given eligibility points, and demand (calculated as the sum of eligibility points associated with the lots for which the bid has bid) cannot increase relative to the preceding round.

Clock auctions allow for easier switching and do not expose bidders to aggregation risks as there are no standing high bids on a subset of the lots on which a bidder placed bids. Clock auctions can also resolve excess demand much more quickly when there are many substitutable lots, as these are grouped into lot categories to which price increments apply uniformly.

However, the clock auction typically uses the same activity rules as the SMRA, where bidders cannot increase their demand relative to the preceding round, and thus switching impediments from eligibility-points based activity rules will remain. As in the SMRA, these impediments can be mitigated through the use of a relaxed activity requirement, but this is only a partial solution.

Coordination problems

A downside of clock auctions is that the flexibility afforded to bidders in terms of being able to switch all of their demand in one go can give rise to coordination problems. This will happen for instance if several bidders who are indifferent between two categories switch at the same time. This problem is reinforced by the price signals provided in the clock auction. We show this in the following example.

Example 4: Coordination problems in a clock auction

> Suppose that we have two lots in each of two categories, and two bidders who want two lots each in one category, but they do not particularly care about which category (or who have a very mild preference for one category). If in the first round both bidders bid for the same category, then there will be excess demand for that category and not the other, so that the price will only increase for one category. In response, both bidders might switch to the other category. This again leads to excess demand in one category but not the other, and to the price increasing in only one category. This alternate increase of prices can continue until one of the bidders stops switching or reduces its demand, possibly resulting in some lots unsold in one category. However, it would have been perfectly possible to accommodate both bidders in the first round.

Unsold lots

In a simple clock auction there is also a risk that demand might drop too abruptly from one round to another (e.g. if several bidders reduce demand in the same round, or if bidders reduce demand by several units in one step). Thus, we might go from a situation in which there is excess demand to a situation in which the auction ends with unsold lots. Such large drops in demand may be the result of price increments being too large or arise from synergistic valuations.

The first cause for large drops in demand can easily be addressed by allowing (or requiring) bidders to make *exit bids* when they reduce demand. These exit bids would be the best offer that a bidder makes for lots on which it ceases to bid. Exit bids specify a price (required to be between the round price in the preceding round and the current round price)[15] at which the bidder would be prepared to buy the lots she no longer demands at the current round price. For example, if a bidder reduces demand from five to two lots, she would specify the price at which she would still demand four lots, and the price at which she would happy to buy three lots. Then, if the auction were to end with excess supply in any lot category, the auctioneer could look into accepting one or more of the exit bids in that category, in which case the price per lot for the category would be dropped to that of the lowest exit bid accepted.

However, allowing bidders to submit exit bids will not address the problem of unsold lots if there is a large drop in demand because of synergistic valuations. Synergistic valuations may result in unsold lots because bidders do not wish to reduce demand progressively and might therefore not be willing to make exit bids for the different intermediate quantities. We illustrate this with an example below.

To mitigate the risk of unsold lots we can ***require*** exit bids, with the additional provision that these exit bids may be honoured only partly: for example, if a bidder reduces demand from five lots, say, to two lots, and makes an exit bid for four lots, this would be taken as a willingness to acquire **up to** four lots at the price specified, even though the bidder may not wish to win three lots at any price above the previous round price. Therefore, this reintroduces aggregation risks by effectively forcing bidders to bid for subsets of lots at the price per lot they offered for a greater number of lots.

[15] For example, suppose that at round prices of 10 per lot a bidder is bidding for three lots. In the following round, when the price increases to 11 per lot the bidder decides to bid for two lots. The bidder could then make an exit bid for a third lot at a price between 10 and 11.

Example 5: Unsold lots in a clock auction owing to synergistic valuations

> Using the same setup as in Example 3, consider now that a clock auction is used instead of an SMRA.
>
> In a simple clock auction (exit bids may be allowed, but not required) bidders do not face aggregation risks, as they can simply withdraw their full demand from one round to another. Therefore, Bidder B could bid for two lots until the price reaches 8, and then exit cleanly. However, this would leave one lot unsold, and Bidder B without any spectrum. This is obviously far from ideal (the auction revenue in this case would only be 18).
>
> Alternatively, one could require exit bids, so that the Bidder B would not be able to drop down demand from two lots to nothing. However, this would reintroduce aggregation risks: if the bidder continues to bid for two lots until the price per lot is 8, then it will be required to also bid for a single lot at a price of 8 or higher. Therefore, the bidder may stop bidding at a lower price. Indeed, if the bidder wants to completely avoid the risk of overpaying it will stop bidding when the price is 4. The auction revenue in this case would be 12.

Restrictions on switching and reducing demand

The risk of unsold lots is also greater if there are multiple lot categories, even when exit bids are allowed or required. For example, bidders may switch without any reduction in activity and would therefore not be reducing demand yet leave the category from which the switch with excess supply. Even if bidders were subsequently required to make exit bids as and when they reduce demand, these bids would not ensure that all the lots in the first category will be sold. To address this problem, some variants of the clock auction (so-called 'clock plus' format as used for recent auctions in Singapore or for the forward auction of the US 600 MHz incentive auction) impose switching restrictions that limit the extent to which switches will be accommodated if they were to leave a particular lot category with excess supply.

More generally, the reason why efficiency cannot be guaranteed in the clock auction is that it requires using linear prices (all lots in a category are sold at the same price). However, in order to assign all the lots, we may need to assign those lots for which there is no demand at the final clock prices at a lower price (where the price *per lot* might depend on the number of lots acquired). In order to support this, bidders would need to be allowed to bid for different 'packages' (i.e. number of lots) at amounts that imply different prices per lot.

One further possibility to address the problem of unsold lots would be to offer any unsold lots in a follow-up process. As the clock rounds would already have provided information to bidders, it would be reasonable to use a sealed-bid process to assign lots that remained unsold in the clock auction. This approach has been adopted by RTR for the upcoming 3.4-3.8 GHz auction.

Variation: clock auction with clinching

The 'clock auction with clinching' is a variant that allows bidders to secure ('clinch') some lots as the auction progresses, at the price at which such lots would remain unassigned if only the other competitors' bids were considered. This introduces a degree of non-linearity of prices, more closely aligned with opportunity cost, as clinched lots are assigned at lower prices.[16]

The rules for this variant are simple and transparent when there is only one lot category and can effectively reduce incentives for stronger bidders strategically to reduce demand. However, the rules become complex when there are multiple lot categories with scope for switching. In this case, when competitors' demand would leave some spectrum unassigned it is not clear which specific lots should be available for clinching, or at what prices. As a result, we do not consider the clinching variant to be appropriate when there are multiple lot categories.

The following table summarises our assessment:

Table 3: Summary assessment of the clock auction

Simplicity, transparency and bidder control over outcomes	Rules are simple, and the process is very transparent. Bidders have to select their preferred lots in each round at the prevailing prices and can switch their demand completely from one package to another (not bound by standing high bids) and easily reduce demand (which eliminates aggregation risks) – unless specific requirements for exit bids are in place.
Aggregation risks	If all bids are package bids, then aggregation risks are eliminated. If provisions exist to require exit bids that can be met only in part, or to retain some bids that the bidder intends to switch, in order to mitigate the risk of unsold lots, then aggregation risks remain.
Substitution risks	The clock auction supports very fluid switching between lots and packages with the same eligibility. However, switching impediments as a result of the activity rule remain, limiting substitution between packages with different eligibility.
Common value uncertainty	Price discovery should help mitigate common value uncertainty.
Strategic complexity	Bidding is very straightforward for bidders with decreasing marginal valuations and who do not need to consider switching between packages. Bid decisions are simplified relative to an SMRA, as bidders only need to specify the number of lots they would like to acquire at prevailing prices rather than select specific lots.

[16] The price at which lots are clinched does not accurately reflect opportunity costs to the extent that it does not consider the value of possible assignments amongst other bidders, but only their aggregate demand at prevailing prices. Where there are strong synergies this may be a poor reflection of the actual value that could be obtained from reassigning each lot.

	As in the SMRA, where there are switching impediments bidders may be subject to substitution risks and may need to rely on their expectations of final prices.
Susceptibility to strategic bidding	Like any pay-as-bid auction there are incentives for strategic reduction of demand. Depending on switching impediments and activity rules, where different types of lots are available bidders may be able to stage competition to resolve first competition for one type, or drive competitors' prices with the aim of reducing their residual budget for other lots. The format typically provides fewer opportunities for signalling than SMRAs.
Price uniformity	All lots within a category are sold at the same price – except in some cases depending on provisions/requirements for exit bids, if lots won with exit bids may be acquired at a lower price. If synergies are strong, then the clock auction may fail to produce efficient outcomes.
Risk of unsold lots	As there are no provisional winners, the risk of unsold lots is potentially high. The risk of unsold lots can be mitigated with provisions and/or requirements for exit bids, or switching impediments, but this may create other inefficiencies. It may be preferable to assign any lots that remain unsold in a follow-up sealed bid round.
Competition safeguards	Works with individual spectrum caps and reservations of specific lots. Can support more complex competition safeguards, but this may increase the risk of unsold lots, unless a combinatorial approach to selecting winning bids is adopted.
Coverage obligations	Works with all the options, but the more flexible approaches (coverage obligations are offered unbundled, or through a default obligation on all lots and exemptions) may involve an appreciable risk of unsold lots/unassigned coverage obligations, unless a combinatorial approach to selecting winning bids is adopted. Can be used for the assignment of coverage obligations in a separate, follow-up stage.
Overall assessment	If all bidders are likely to pursue lots in all categories rather than switch between them, then a clock auction would be appropriate even if there are some synergies between lots, with provisions for exit bids and/or a follow up process to mitigate the risk of unsold lots. It could also be used for the assignment of coverage targets in a follow-up stage. For the more flexible approaches to assigning coverage obligations and setting competition safeguards, the clock auction is only safe if a combinatorial approach is adopted for the evaluation of bids. However, in this case it may be preferable to use a CMRA instead (discussed below), which extends the clock auction providing

	bidders with greater flexibility and eliminating aggregation and substitution risks.

3.2.4 Clock-SMRA hybrid formats

Requiring exit bids that may only be partially fulfilled and restricting switching or withdrawals makes the clock auction more SMRA-like without explicitly introducing the notion of standing high bids and standing high bidders. However, these constraints expose bidders to the same risks and limitations that arise from the notion of standing high bidders in the SMRA.

An alternative approach to amalgamating these two formats together is explicitly to declare standing high bidders for the lots available, whilst retaining the pricing mechanism of the clock auction where in each round the auctioneer sets the same price for all of the lots in a given category, and any new bids for lots must be at these prices. This approach has been used successfully in a number of spectrum awards in India, and recently in the United Kingdom for the award of spectrum in the 2.3 GHz and 3.4 GHz bands.

Under this format, bidders do not place bids on specific lots, but simply state the number of lots in each category for which they want to bid at the round price. Standing high bids can then be selected with a view to minimising the number of bidders whose demand is only partially satisfied (i.e. for whom only part of their bids become standing high bids), which mitigates aggregation and substitution risks at least to some extent. This format also offers the possibility for standing high bidders to wait to be outbid before raising their bids.

More specifically, these hybrid formats typically work as follows:

- The auctioneer specifies clock prices for each lot category, and bidders specify the number of lots for which they wish to make bids at that price in each category.
- At the end of each round, the auctioneer selects standing high bidders in each lot category – in order to minimise the number of bidders who may receive fewer lots than they bid for, this can be done by ordering bidders (using pre-specified criteria or at random) and satisfying their demand in turn until there are no more lots available, so that for each of the lot categories at most one bidder will hold standing high bidder on only a subset of the lots requested.
- If all of the lots in a category have a standing high bid at the clock price, then the clock price for the following round is increased.
- Standing high bidders can keep their standing high bid unchanged or increase it to a higher clock price.

- Activity rules apply as in an SMRA (i.e. both new bids and unchanged standing high bids count towards activity).

This approach has the advantage of progressing more quickly if there is a small amount of excess demand for a large number of lots, and, depending on the specific rules, producing uniform prices for similar lots rather than the (roughly) similar prices that typically emerge in an SMRA. Essentially, the clock-SMRA hybrid provides flexibility to blend these two formats to achieve a balance between mitigating aggregation and switching risks, mitigating the risk of unsold lots, and simplifying bidding decisions by offering similar lots in categories.

The following table summarises our assessment:

Table 4: Summary assessment of the clock-SMRA hybrid

Simplicity, transparency and bidder control over outcomes	Although this format has not been as widely used as the standard SMRA and clock auctions, the rules are very similar to those of these two formats, and can retain a high degree simplicity transparency, and a similar degree of control as the SMRA.
Aggregation risks	The extent to which bidders are exposed to aggregation risks depend on the specific rules adopted. The determination of standing high bids introduces aggregation risks. However, standing high bids can be selected with a view to minimising the number of bidders that may have their bids only partially accepted.
Substitution risks	Switching impediments are greater than in a pure clock auction due to standing high bids. As in the SMRA and clock auctions, switching impediments continue to arise as a result of the activity rule when switching between heterogeneous lots, and if alternative packages of interest have different eligibility.
Common value uncertainty	Price discovery should help mitigate common value uncertainty.
Strategic complexity	As with the previous two formats, bidding is very straightforward for bidders with decreasing marginal valuations who do not need to consider switching between packages. Like in a clock auction, bid decisions can be simpler than in an SMRA, as bidder do not need to select specific lots. However, switching decisions might be more complex due to the possibility that bidders may have standing high bids. As with the previous two bidders, expectations may play an important role in bid strategy, so there is a risk of inefficiencies if such expectations are wrong.
Susceptibility to strategic bidding	The scope for strategic bidding is similar to its ancestors, though possibly more aligned with those in a clock auction. As bidders do not make bids on specific lots, there may be less opportunity for signalling than in an SMRA, but other risks remain.

Price uniformity	All lots within a category are sold at similar prices (within one price increment. If synergies are strong, then the clock auction may be inefficient.
Risk of unsold lots	As in the SMRA – these are related to any potential provisions for withdrawal of standing high bids. If withdrawals are not allowed, or may involve significant costs, then the risk that lots will go unsold is low.
Competition safeguards	Works with individual spectrum caps and reservations of specific lots. Unlike the SMRA, the clock-SMRA hybrid may support somewhat more complex competition safeguards, as it provides greater flexibility for the selection of standing high bids.
Coverage obligations	As the clock auction, it would work with all the options, but the more flexible approaches (coverage obligations are offered unbundled, or through a default obligation on all lots and exemptions) may involve a high risk of unsold lots/unassigned coverage obligations, unless a combinatorial approach to selecting provisionally winning bids is adopted. Can be used for the assignment of coverage obligations in a separate, follow-up stage.
Overall assessment	We would recommend using a clock-SMRA hybrid if the basic structure and simplicity of the SMRA is desired, but there are many lots on offer that can be grouped into a small number of categories of almost similar lots. The clock-SMRA hybrid also improves on the SMRA by allowing for the possibility of reducing the number of bidders who may hold standing high bids on only a subset of their target lots. For the more flexible approaches to assigning coverage obligations and setting competition safeguards, the clock-SMRA auction may be severely limited unless a combinatorial approach is adopted for the evaluation of bids, but such approach would undermine the simplicity and predictability associated with the SMRA.

3.2.5 Combinatorial Clock Auction (CCA)

A CCA is structured as a simple clock auction followed by a sealed-bid combinatorial round in which bidders are subject to constraints that arise from the bids they have made during the clock auction. The rationale for this is that:

- the final sealed-bid round eliminates aggregation and substitution risks by permitting bidders to express a full demand profile in a list of mutually exclusive package bids; and
- the initial clock auction phase provides information to bidders about demand, thus reducing the uncertainty they will face in the final sealed-bid round relative to a simple sealed-bid auction.

CCA bidding process

The process starts as a simple clock auction, as follows:

- identical lots are grouped together into lot categories;
- the auctioneer announces the price for each lot category in a round, and bidders specify the number of lots in each category they wish to acquire at the prices announced by the auctioneer;
- if there is excess demand for any of the lot categories (i.e. if the total number of lots that bidders indicated they wish to acquire at the round price exceeds the number of lots available), then a further round needs to be run, with a higher round price for lot categories that had excess demand; otherwise the clock auction phase ends.

The clock phase is followed by a single round (the 'supplementary bids round') in which bidders can make additional, mutually exclusive bids for alternative packages (subject to constraints arising from the activity rules outlined below).

The winning bids are then selected from all of the bids received in the auction. The selection of winning bids can adopt different bidding or outcome constraints and will typically use an opportunity-cost based pricing rule (similar to a second price rule in a single-item auction, but adapted for the case of multiple items).

The more basic activity rules for the clock phase are identical to those in a simple clock auction, where demand (calculated as the sum of eligibility points associated with the lots for which the bid has bid) cannot increase relative to the preceding round.

Each time a bidder reduces demand, this will provide information about preferences as, at round prices, the bidder obviously prefers the smaller package to any of the larger packages on which it could have placed bids. This information will be used to create so-called 'relative caps' on bids that can be placed in the supplementary round relative to the amount of the bid for the package on which the bidder bid when reducing demand.[17] These constraints are aimed at tying the supplementary bids a bidder can place to its behaviour during the clock rounds.

The CCA can adopt a relaxed activity rule for the clock phase, which will allow bidders to increase their demand (in terms of eligibility points) relative to the preceding round if doing so is consistent with the relative caps. Effectively this allows bidders to make bids that they would have been able to do in the supplementary bids round, and improves the information disclosed during the clock phase.

[17] The revealed preference constraint is set with reference to choices made by the bidder. Specifically, suppose that a bidder selects package X over package Y when round prices are P_X and P_Y. A revealed preference constraint in relation to this choice would constrain the bid for Y to be at most the bid for X plus P_Y-P_X. This means that the bidder may need to raise its bid for X in order to also raise its bid for Y above the prices that applied when it made the constraining choice.

Additional revealed preference constraints arise in the final round of the clock phase. If the basic activity rule is used for the clock phase, these caps will only affect packages with eligibility equal to or lower than the bidder's bid in the final clock round. If the relaxed activity rules are used, then this cap affects all packages, effectively requiring that the bidder will have to satisfy revealed preference with respect to the final clock round in all its bids.

The CCA has a number of desirable features:

- there are no aggregation risks in a CCA, as bids are submitted for indivisible packages of lots;
- switching and coordination impediments are removed by allowing bidders to make a list of mutually exclusive bids;
- an efficient outcome is possible even if there are synergistic valuations, as prices are not bound to linear prices.

However, the mechanics of the CCA are clearly more complex than those of the SMRA or the simple clock auction. This can create discomfort for bidders and increase the scope for mistakes, especially if bidders try to second-guess competitors in order to bid strategically to distort the outcome in their favour.

Uncertainty in the CCA

Many bidders have also expressed discomfort with respect to the sealed-bid aspect of the auction, which exposes to uncertainty about the lots they will eventually win and the price they may need to pay. The level of uncertainty is greatly reduced when the relaxed activity rules are used. However, these rules also increase the mechanical complexity of the process. Furthermore, it is still possible in some cases that a bidder who has made bids at the final clock round prices may eventually fail to win any spectrum at all after the supplementary bids round – such outcome is efficient in that it involves a better assignment of the available lots, but bidders who would leave empty-handed might then find that they would consider changing their bids to try to win some spectrum.

Bidders have also objected to the opportunity cost based pricing rule used in the CCA on the grounds that:

- it creates governance problems for bidders, as the optimal bid strategy may require making bids that are much higher than what the bidder expects to eventually have to pay, but these decisions are difficult to make and sign off;
- it poses challenges who are subject to a relatively tight budget constraint, who will need to focus their bids according to their expectation of what they expect to be able to win within their budget;
- it provides incentives for bidders to make bids they do not expect to win in order to increase the price that competitors will have to pay; and
- can lead to asymmetric prices, which can be difficult for bid teams to justify to the company board and/or shareholders.

Despite these concerns, the CCA remains an efficient auction format that is particularly suited for multi-band auctions. It can be expected to perform very well provided that bidders have budgets that reflect their actual valuations and that they have the means to prepare for and bid during the auction.

The ECCA

In order to address some of the concerns raised in connection with the CCA (in particular the relevance of the outcome of the clock rounds for the final assignment of lots, and the scope for strategic bidding), proposals for a so-called Enhanced CCA ('ECCA') have been put forward. The most fully articulated description of the specifics of the rule can be found in the consultation document issued by the Canadian Department for Innovation, Science and Economic Development (ISED).[18] The core modifications relative to the CCA are that a stricter activity rule is used for both the clock rounds and the supplementary round, and a modified pricing rule.

The activity rule of the ECCA permits bidders to submit bids for package that exceed their eligibility, but only if all of the bids submitted by the bidder since the last round in which it had sufficient eligibility to bid on this package are consistent with truthful bidding based on some implied set of valuations.[19] The requirement of consistency of all bid decisions from the round in which the bidder would last have been able to bid on a particular package based on its eligibility with an underlying set of valuations is also extended to supplementary bids. Overall, the activity rule of the ECCA imposes tighter constraints on the additional bid amounts that can be placed on larger packages.

Given these tighter constraints, the ECCA rules then determine prices on the highest valuations that bidders could possess, given the bids that they have made. Put simply, rather than using the bids actually placed, the ECCA pricing rule considers the maximum bids that could have been placed by other bidders for larger packages that incorporate the lots on which a bidder places bids (and eventually on the winning package), given those bidders' bidding history. This means that in the clock rounds bidders will before each clock round be informed about the amount by which their base price would be lower than their bid, based on the choices made by other bidders so far. Should the clock round end without any unsold lots, prices would simply be determined by applying the respective discounts to the final clock bids (i.e. calculating the most that other

[18] Consultation on a Technical, Policy and Licensing Framework for Spectrum in the 600 MHz Band, August 2017, Annex C (available at www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11316.html)

[19] This requirement is derived from the General Axiom of Revealed Preference (GARP), and therefore these activity rules are referred to as GARP-based activity rules. To establish whether bids in excess of a bidder's eligibility meet this condition, the auctioneer checks whether there is a set of valuations for different packages under which all bidding decisions made in these rounds can be interpreted as maximising surplus (i.e. the difference between the underlying valuation of a package and its round price).

bidders could possibly bid for the lots won by a particular bidder) without the need for running a supplementary round (which, by implication, would only be needed if there were unsold lots at the end of the clock stage). These modifications are intended to make the clock stage more relevant and limit the role of the supplementary round to assigning lots that might otherwise remain unsold and to reduce the scope for strategic bidding, thus improving price discovery.

The following table summarises our assessment:

Table 5: Summary assessment of the CCA

Simplicity, transparency and bidder control over outcomes	The CCA has complex mechanics, in relation to the application of activity rules, the selection of winning bids and the determination of prices. The second-price rule can lead to material price asymmetries, which may be necessary for efficiency purposes, but may also raise concern amongst bidders. It also features a sealed-bid element that, despite the fact that information revealed during the clock rounds should greatly reduce the uncertainty faced by bidders, can create substantial concerns about the risk of leaving the auction empty-handed or paying much more than competitors.
Aggregation risks	The CCA eliminates aggregation risks.
Substitution risks	The CCA provides an opportunity for bidders to avoid substitution risks, by submitting a sufficiently rich set of bids that reflects their demand for alternative packages. However, some bidders might be subject to residual substitution risks if they cannot reflect valuations in their bids, e.g. if they face budget constraints or if there is a cap on the maximum number of bids that bidders can make.
Common value uncertainty	Price discovery should help mitigate common value uncertainty.
Strategic complexity	As it relies on opportunity-cost based pricing, the CCA reduces the concerns about bid shading that would otherwise affect the sealed bid stage (though it does not fully eliminate them).[20] Where bidders have to narrow the set of bids they make (e.g. due to budget limitations), the trade-offs are potentially complex, and depending on the objectives (see below) gauging the implications of clock bid choices for the scope of supplementary bids that can be placed can be difficult.
Susceptibility to strategic bidding	Whilst the second price rule greatly reduces incentives for strategic demand reduction, it can create incentives for bidder to overstate their demand for additional lots in order to drive rivals' prices. Bidders may also have

[20] Some residual concerns remain owing to the requirement that each group of winners pays their joint opportunity cost, which means that the amount bid by an individual bidder may have an impact on the price that it pays through the rule that determines how any excess of joint opportunity costs of a group over the sum of the individual opportunity costs of each member is shared out.

	incentives to maintain eligibility until late in the auction to retain greater flexibility for their supplementary bids (which they may want to have if they intend to make price-driving bids, or if they are highly uncertain about their initial valuations). Bidders may also have incentives to suppress bids for small packages in order to increase their chance of winning larger packages at a lower price.
Price uniformity	The CCA allows for asymmetric prices, which can promote efficiency and reduce the risk of unsold lots.
Risk of unsold lots	Provided that bidders submit a rich set of bids covering all packages of interest, the CCA will succeed in assigning lots whenever it is efficient to do so.
Competition safeguards	All approaches work in a CCA, including those that require outcome restrictions. However, if outcome restrictions are used, additional measures may be appropriate to limit the risk that bidders may leverage such constraints.
Coverage obligations	All approaches work in a CCA, including those that require outcome restrictions. However, if outcome restrictions are used, additional measures may be appropriate to limit the risk that bidders may leverage such constraints. Can be used for the assignment of coverage obligations in a separate, follow-up stage.
Overall assessment	We would consider the CCA as a candidate for awards where many lots are offered, where demand for different lots is likely to be interrelated and where synergies are likely to be material. The CCA will effectively mitigate aggregation risks. The CCA is also appropriate when outcome restrictions are used for implementing sophisticated measures to safeguard competition or for the assignment of coverage lots. However, it does introduce some other uncertainties for bidders, and may be particularly challenging for bidders with a limited budget.

3.2.6 Combinatorial Multi-Round Ascending (CMRA)

The CMRA builds on the CCA with relaxed activity rules for the clock auction phase. However, the CMRA suppresses some elements of the CCA in relation to which bidders have expressed concern, bringing it closer to a clock auction:

- it does not have a final sealed-bid round – instead, it allows bidders to make multiple bids in each clock round (subject to the constraints that would apply to the supplementary bids

round of the CCA) and runs a combinatorial evaluation of bids at the end of each round;
- it does not expose bidders to the risk of not winning any spectrum unless they explicitly stop making bids at round prices; and
- it uses a pay-your-bid rule instead of the opportunity cost based pricing rule used in the CCA.

In essence, the CMRA is a clock auction where bidders may submit multiple bids in each round, one of which must be a clock prices, and the rest which cannot exceed round prices (and must comply with activity rules).

CMRA bidding process

The process follows the multi-round structure of a clock auction, in that:

- identical lots are grouped together into lot categories;
- the auctioneer announces the price for each lot category in a round, and bidders specify the number of lots in each category they wish to acquire at the prices announced by the auctioneer – this constitutes the ***headline bid*** of the bidder in that round.

However, bidders can also make ***additional bids*** in each round, subject to the constraint that none of these bids can exceed the round price, and that relative caps that arise from previous headline bids are satisfied. These relative caps arise when a bidder reduces its eligibility by bidding on a headline bid with less eligibility that its preceding one, following the same approach as in a CCA.

Another difference is that the auction does not end when there is no excess demand at round prices in any category, but rather when the optimal outcome given the bids received so far (using a combinatorial evaluation of bids analogous to that used after the supplementary bids round in a CCA) involves accepting a bid from each bidder – these become the winning bids and bidders pay the amount of their bid.

The closing rule differs from that in a clock auction in that the auction might continue even if there is no excess demand at round prices. However, this will only happen if any of the bidders who is still bidding at round prices would be outbid with the bids made so far. At the same time, it is also possible that the auction might end when there is still excess demand at round prices, provided that it is possible to accept a bid from each bidder by considering their additional bids.

The CMRA adopts the relaxed activity rules developed for the CCA, which allow bidders to increase their demand (in terms of eligibility points) relative to the preceding round if doing so is consistent with the relative caps. This allows bidders to make bids that they would have been able to do in the supplementary bids round of a CCA.

The CMRA has some of the desirable features of the CCA:

- there are no aggregation risks in a CMRA, as bids are submitted for indivisible packages of lots;
- switching and coordination impediments are removed by allowing bidders to make a list of mutually exclusive bids each round, and by allowing bidders to increase their demand in response to price movements;
- an efficient outcome is possible even if there are synergistic valuations, as prices are not bound to linear prices.

However, the CMRA provides greater control to bidders with respect to the possible final outcome, by allowing them to increase the number of packages on which they bid without the fear of leaving the auction empty-handed if they do not submit a large number of package bids. If additional packages are introduced progressively as winning others becomes less and less likely, the additional flexibility does not automatically translate into greater uncertainty.

The CMRA also provides certainty about the price to be paid and does not require (or allow) bidders to make bids above round prices, ensuring that bidding is progressive and predictable.

The mechanics of the CMRA are clearly more complex than those of the SMRA or the simple clock auction. As with the CCA, this can create discomfort for bidders and increase the scope for mistakes, especially if bidders try to second-guess competitors in order to bid strategically to distort the outcome in their favour.

The CMRA is also subject to the problems that affect any pay-as-bid format, namely that they may

- try to shade their bids (i.e. bid below their true valuation) with a view to maximising their surplus (i.e. the difference between their valuation and the price paid); and
- have an incentive to reduce demand early in order to win some lots at a lower price.

However, the incentives to reduce demand in headline bids is (partly) mitigated through allowing bidders to make additional bids below round prices.

The CMRA should perform well for multi-band auctions and should be less affected by some bidders having to bid to a tight budget constraint.

In addition, the CMRA can be adjusted to mitigate the risk of highly asymmetric prices, by discarding bids that fall below a certain threshold relative to prevailing clock prices (except those that are essential for the implementation of activity rules). This will cancel out some of the benefits from allowing for the possibility of non-uniform prices across lots but may reduce concerns that bidders may have to pay very different prices for similar winnings, and perceived relative performance of different bidders.

The following table summarises our assessment:

Table 6: Summary assessment of the CMRA

Simplicity, transparency and bidder control over outcomes	The CMRA has complex mechanics in relation to the application of activity rules and the selection of winning bids. However, it uses a simple first-price rule for the determination of prices, which is a significant simplification relative to the CCA. The CMRA can also be adjusted to reduce the scope for price asymmetries. Another key element of the CMRA is that it does not have a final sealed-bid round, but rather uses a closing rule that ensures that active have an opportunity to bid back and will not leave empty-handed unless they explicitly accept this outcome. This means that bidders retain control over their outcome and an decide whether they want to offer additional flexibility in exchange for lower prices. Bidders can bid in a CMRA in the same way as in a simple clock auction if they wish to do so.
Aggregation risks	The CMRA eliminates aggregation risks.
Substitution risks	The CMRA provides an opportunity for bidders to avoid substitution risks, by submitting a sufficiently rich set of bids that reflects their demand for alternative packages. It also assists bidders who do not want to bid for many packages or who face budget limitations, by allowing them to discard targets progressively and switch to new ones. Considering bids submitted in earlier rounds means that the CMRA further reduces substitution risks and coordination problems
Common value uncertainty	Price discovery should help mitigate common value uncertainty.
Strategic complexity	The CMRA should be strategically simple as bidders always have the option of bidding as in a simple clock auction. The format uses a first-price rule, so there is no additional complication related to making bids to set competitors' prices.
Susceptibility to strategic bidding	The first-price rule removes incentives for bidder to overstate their demand for additional lots in order to drive rivals' costs, allowing them to focus on their own results. The obvious flipside is that there are incentives to reduce demand to keep prices down (albeit somewhat mitigated by the fact that bidders may submit bids for smaller packages at prices that are lower than prevailing clock prices).
Price uniformity	The CMRA allows for asymmetric prices, which can promote efficiency and reduce the risk of unsold lots. At the same time, it allows for the possibility of reducing the scope for asymmetries if there is some concern that highly asymmetric prices could adversely affect operators.
Risk of unsold lots	Provided that bidders who reduce demand consider suitable alternatives and make relevant bids, the CMRA will succeed in assigning lots whenever it is efficient to do so.

Competition safeguards	All approaches work in a CMRA, including those that require outcome restrictions. However, as in the CCA, if outcome restrictions are used, additional measures may be appropriate to limit the risk that bidders may leverage such constraints.
Coverage obligations	All approaches work in a CMRA, including those that require outcome restrictions. However, as in the CCA, if outcome restrictions are used, additional measures may be appropriate to limit the risk that bidders may leverage such constraints. Can be used for the assignment of coverage obligations in a separate, follow-up stage.
Overall assessment	The CMRA is suitable for a wide range of situations. In simple settings (i.e. one lot category), the mechanics of the CMRA will be simple, comparable to those in a clock auction, but with additional flexibility to make and process bids under a combinatorial approach. In more complex settings, the CMRA may be preferable to a CCA when some bidders face tight budget limitations, or may not necessarily bid with a view to maximise surplus, but rather following a hierarchical approach to selecting their targets. However, the CMRA could be challenging with many lots and possible packages if bidders want to offer maximum flexibility round-by-round.

4 Suggested auction formats

Award scenarios

The suitability of different auction formats for the award depends on:

- the lots included in the option (and in turn the structure of demand for the lots available),
- the measures selected to safeguard competition; and
- the approach taken for the assignment of coverage obligations.

In terms of the lots included, the key questions are:

- whether all three bands are available for the award, or whether there will be separate awards of 2100 MHz and 700/1500 MHz; and
- whether multiple bands included in the same award (i.e. all bands, or the 700/1500 MHz bands in the case where 2100 MHz needs to be awarded earlier) should be offered in a single stage, or whether the award process should be split into different stages.

The first question is decided by the time at which the 700 MHz spectrum will become available, and the extent to which it may be possible to include frequencies that might not be usable for a period of time in an award process.

The answer to the second question depends mainly on considerations of complexity.

In terms of competition safeguards, we can broadly distinguish between spectrum caps and more complex outcome restrictions.

Regarding the assignment of coverage obligations, the three options are to link these to specific spectrum blocks or assign them separately from spectrum, and in the latter case including both spectrum and coverage obligations into the same bidding phase or assigning spectrum and coverage obligations in separate stages (where it is also possible to use combinations of these approaches, e.g. assigning 'basic' coverage obligations, potentially tied to specific spectrum blocks, within the process for assigning spectrum, and 'additional' coverage obligations in a follow-up process, in exchange for a discount on the price of spectrum).

Guiding principles for our recommendation

This leaves us with a large combination of potential scenarios. However, from the discussion above we can distil some principles that should guide the choice of format:

- For the assignment of spectrum lots, we generally recommend using an open format in order to mitigate the uncertainty faced by bidders and minimise the scope for bidding mistakes and challenges of the process. One possible exception would be the separate award of 1500 MHz in multiple categories, where a combinatorial sealed bid might provide an attractive operation for implementing bidding constraints that ensures, to the greatest possible extent, contiguity of assignments.

- If there are strong synergies in the underlying valuations, a combinatorial approach is highly desirable. Such strong synergies may exist across the different blocks within a band, across bands and across spectrum and coverage lots. This would strongly suggest the use of combinatorial formats for any approach in which coverage obligations were to be assigned separately from, but alongside spectrum (which is presumably reflective of the view that there are strong synergies), or where there are strong complementarities across spectrum bands.
- The use of outcome restrictions to safeguard competition would suggest that there are benefits from using auction formats in which bids are evaluated jointly rather than on a lot-by-lot basis, as this is required for any meaningful implementation of constraints on outcomes.
- When linking coverage obligations to specific lots, this implies an increase in the number of lot categories that would need to be included in the process. In terms of complexity, and all other things being equal, this would tend to shift the balance more towards using simpler formats such as the SMRA. On the other hand, in particular where such lots had a different size, this may create switching impediments in formats that rely exclusively on eligibility-points based activity rules, which in turn would suggest the use of a combinatorial approach. Whether these shifts are sufficient to affect the choice of format depends on the strength of underlying synergies.
- We would give preference to the SMRA-Clock hybrid over the SMRA on account of the fact that it provides some more scope for limiting aggregation risks by ensuring that within each category at most one bidder holds standing high bids on only a subset of the lots it wishes to acquire.
- On grounds of certainty and control over outcomes, we would give preference to the CMRA over the CCA (including the ECCA), noting, however, that the format has met with objections on account of its novelty. We believe that it might be desirable to try better to understand the reason underlying these objections and to see whether they could be overcome through more engagement with stakeholders.
- For the assignment of coverage obligations separately from spectrum (and in a separate bidding phase) it should be possible to use a simple sealed bid approach, given that any common value component should be fairly limited. Unless there are strong scale economies in meeting combinations of obligations, there may be no need for a combinatorial format, and winners could be decided on a per-lot basis.
- The uncertainties faced by bidders with respect to the assignment of specific frequencies are limited, in that bidders are guaranteed a range of a specific bandwidth within a

frequency range across which all blocks are deemed to be of equal value. Therefore, the assignment of specific frequencies can be done through a simple sealed-bid process. Specifically, we recommend that a sealed-bid, second price, combinatorial auction be used, as in previous spectrum auctions in Austria.

4.1 Award of all three bands in a single stage

The following table provides an overview of the suggested formats derived from the principles set out above for the case where all bands available for award are to be offered together in a single stage, i.e. where the 700 MHz band is available sufficiently early to be included in an award that is sufficiently timely for the assignment of the 2100 MHz spectrum and where there is no need to split the award into separate stages to manage complexity.

Table 7: Suggested auction formats for combined award of all three bands

	Only spectrum caps	Outcome restrictions
Coverage obligations linked to specific spectrum lots	CMRA or CCA if there are strong synergies, SMRA-Clock hybrid otherwise	CMRA or CCA in order effectively to implement outcome restriction
Coverage obligations separate from spectrum, but offered alongside spectrum in the same bidding process	CMRA or CCA in all cases to address aggregation risks between spectrum and coverage obligation lots	
Separate assignment of coverage obligations after the award of spectrum	For the assignment of spectrum: CMRA or CCA if there are strong synergies, SMRA-Clock hybrid otherwise	For the assignment of spectrum: CMRA or CCA in order effectively to implement outcome restriction
	For the assignment of coverage obligation: combinatorial or non-combinatorial sealed bid, depending on the extent to which there are synergies across obligations (assuming that the number of obligations would be small and the number of potential combinations would therefore limited)	

In summary, we consider that a combinatorial process would be required if any of the following conditions holds:

- there are strong synergies across frequencies in the different bands;
- spectrum caps alone are not suitable and the inclusion of more complex competition safeguards is required; or
- coverage obligations should be decoupled from individual spectrum blocks, but should be offered alongside spectrum rather than separately.

4.2 Separate award of 2100 MHz

If the 2100 MHz band had to be offered separately before the remaining frequencies could be awarded, we consider that the award of the 2100 MHz band could be made using an SMRA-clock hybrid format, unless outcome restrictions were required to safeguard competition, or separate coverage obligation lots had to be offered alongside the spectrum. Otherwise, a combinatorial process would ideally be used. This is because strong synergistic valuations beyond the spectrum endowments that might need to be guaranteed to ensure business continuity are unlikely.

At this point, we would not envisage there to be any strong need for outcome restrictions or for assigning separate coverage obligations alongside the spectrum in this band, and therefore the simple SMRA-clock hybrid format would be appropriate.

For the later award of spectrum in the 700 MHz and 1500 MHz bands, the same considerations as set out above in Section 4.1 would apply.

4.3 Offering bands in separate stages

We do not consider that it should be necessary to split the spectrum award process into different stages for reasons of complexity when looking purely at the number of lot categories, even if all three bands were to be included and if the 1500 MHz band had to be offered in three separate lot categories (lower extension band, core band, upper extension band).

Offering 1500 MHz in a separate stage

However, should there be concerns about complexity, it should be fairly straightforward to split out the award of the 1500 MHz band into a separate stage that follows the assignment of 2100 MHz and 700 MHz (or of 700 MHz, if the 2100 MHz band had to be offered earlier in a separate award).

In this case:

- the award of spectrum in the 1500 MHz band could take the form of a clock auction or a combinatorial sealed bid auction, with the latter supporting bidding restrictions that maximise the likelihood that contiguous frequency assignments could be made despite the split of the band into three categories;
- where all bands are available in the same award process, the same considerations as set out above in Section 4.1 would apply for the combined award of 700 and 2100 MHz;

- if only 700 MHz were included because the 2100 MHz band has been awarded previously, a combinatorial approach would be required if outcome constraints were to be used or coverage obligations were to be assigned unlinked from, but alongside spectrum – otherwise, an SMRA-clock hybrid format should work well.

Suggestions for a staged process that minimises the complexity of efficiently assigning spectrum and coverage obligations and safeguarding competition

Moreover, it may be possible to separate the award process into different stages in order to facilitate the pursuit of ambitious coverage targets whilst guaranteeing that each bidder has the opportunity to acquire a minimum spectrum endowment.

The idea here would be to express the coverage targets in the form of a number of separate obligations, and assign these (and potentially access obligations that might be deemed to be desirable to promote downstream competition) to larger spectrum blocks, which would then be offered with the constraint that each bidder will be allowed to acquire at most one block in a first stage. When bidding for these blocks, bidders would essentially compete for the different obligations rather than the underlying spectrum. Each bidder is guaranteed a sizeable spectrum endowment, ***provided that it is prepared to take on one of the obligations***, which means that there is an effective spectrum floor on the auction outcome.

The award of the combination of spectrum and coverage obligation in this stage could take the form of a standard SMRA, given the limited number of blocks on offer and the fact that each bidder can acquire at most one block.

The 700 MHz band would seem to be the natural candidate for the first stage, given that its propagation characteristics are most suited for the provision of coverage. Awarding 700 MHz spectrum first also means that the complementarity between sub-1 GHz paired spectrum and the 1500 MHz SDL spectrum is captured through the appropriate sequencing.

The remaining spectrum would then be offered (possibly subject only to the basic coverage obligations) that have to be met by all bidders in a second stage. In this stage, spectrum caps should be sufficient to prevent outcomes that could undermine competition, given that bidders would have had the opportunity to obtain sizeable spectrum resources in the first stage. Should any of the spectrum offered in the first stage remain unassigned, it would be included in the second stage, either with the same additional coverage obligations as in the first stage, or without obligations, but split into smaller blocks. In both cases, it would be necessary to adjust spectrum caps so that bidders who have acquired spectrum in the first stage would not be excluded from bidding on these blocks.

The auction format could be combinatorial (i.e. CMRA or CCA) if there are strong synergies across the bands offered in this stage (which is unlikely if the 700 MHz band has been offered in the first stage), or it could be an SMRA-clock hybrid.

A third stage would then be conducted to assign specific frequencies to the winners of spectrum in the first two stages.

Further coverage targets could be offered in a fourth stage, where winners of spectrum can offer to take on additional obligations in exchange for a reduction in their spectrum fees. Should spectrum that remained unassigned in stage one be included in stage two without the initial obligations, then these obligations could also be included in this fourth stage. Depending on the number and nature of additional coverage targets, this stage could be run as an SMRA, or as a combinatorial or non-combinatorial sealed bid process.

This four-stage model is a variation of the approach used by the Danish Energy Agency for the award of 1800 MHz spectrum (though this process did not include the option of bidding for additional coverage targets), and suggested for the award of spectrum in the 700, 900 and 2300 MHz bands. The main difference, however, is that the obligations linked to the different spectrum blocks in the first stage do not have to be similar. Instead, the first stage would be used to assign different types of obligations to different winners.

This four-stage process would of course eliminate competition for (incremental) spectrum in the 700 MHz band; the distribution of frequencies in this band is determined by the definition of the blocks to be offered in the first stage. Consequently, it would also limit the scope for substitution between 700 MHz and 2100 MHz spectrum. Both of these factors suggest that there could be a loss of efficiency. However, any such loss may be small given that the scope for competition for 700 MHz spectrum may need to be constrained in any case in order to protect competition in the downstream market. At the same time this staged approach avoids the need for complex outcome restrictions (which should become unnecessary with the opportunity to acquire a sizeable block of spectrum in the first stage) and can work with simple auction formats throughout. On balance, it should therefore be compatible with the award objectives set out above.