

Incentive Auction Rules Option and Discussion

Submitted by *Auctionomics and Power Auctions*
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The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the Federal Communications Commission.

1. Introduction

Auctionomics and Power Auctions have submitted this exhibit to the Incentive Auction NPRM at the request of the Commission's staff. Its purpose is to elicit more focused comments and to present a specific option that integrates all the key elements of the Incentive Auction design for television broadcast spectrum. There may well be other options that also are likely to achieve the goals of the Incentive Auction.

The Incentive Auction has three distinct components. One is a *Reverse Auction*, in which television broadcasters may offer to relinquish certain broadcast rights in exchange for cash compensation. These relinquishments may include going off-air, sharing a channel, or moving to a lower broadcast television band. The second component is a *Forward Auction*, in which bidders may offer to buy newly created flexible use licenses. The Reverse and Forward Auctions are connected by a third component, the *Clearing Rule*, which sets and revises the quantities to be transacted in the Reverse and Forward Auctions and determines when the Incentive Auction as a whole should end.

All three parts of the design raise novel challenges and in this document we present an auction design option that addresses each of these components.

Reverse Auction: Broadcasters bid to voluntarily relinquish spectrum rights

For the Reverse Auction, the most unusual challenge arises because the quantity of spectrum cleared depends not only on the broadcast licenses relinquished in the auction but also on how the remaining broadcast stations – the ones that are *not* sold – are assigned to channels. Additional complications arise because the Reverse Auction must account for more possibilities than simply selling broadcast rights. In exchange for compensation, some stations may be willing to switch from broadcasting on a UHF channel to broadcasting on an upper VHF or lower VHF channel; others may be willing to engage in channel-sharing, combining their digital signals to be carried on a single channel; and still others may be willing to tolerate some increase in the area where their signals suffer interference.

Despite these complexities, the auction process needs to be simple and easy enough to encourage and facilitate the participation of a wide array of broadcasters. In particular, the auction we propose – a descending clock auction – is designed to make it very easy for broadcasters to make optimal bids.

As a simple example of how the descending clock auction works to clear a fixed number of channels, suppose that the FCC needs to clear three stations in some market and that five stations have indicated a willingness to sell at the reserve price. Suppose that all five stations are broadcasting from the same location, so clearing any three would meet the FCC's needs. During the auction, the FCC offers a sequence of declining prices until one station says "no." At that point, four stations are still offering to go off-air, and the FCC just needs three, so there is still excess supply. The FCC continues to lower the offered price until a second station says "no." At that point, just three stations remain. There is no longer excess supply, so the auction

ends. The two stations that exited the auction are assigned channels, and the three remaining stations are paid the last offered price to go off-air.

More generally, stations within a market may have different coverage areas, so they are not fully interchangeable as in the simple example. Also, bidders may offer to move to a lower band, e.g. from UHF to upper VHF, rather than offer to go off-air. Nevertheless, the auction will look similar from the broadcasters' perspective.

Prior to the auction, the FCC will set a reserve price or maximum payment for going off-air and also reserve prices for moving to a lower band. To participate in the auction, a broadcaster must choose at least one option at its reserve price. As the auction proceeds, the FCC will offer the broadcasters progressively lower prices. Once a broadcaster says "no" to its current offers, it exits the auction and is guaranteed a channel in its pre-auction band. As this happens, the FCC will check every active bidder to determine whether it still would be possible to assign that bidder to its pre-auction band, given the set of bidders that have exited so far. For those active bidders whose exit is feasible, the price offers for different relinquishment options may be reduced with the goal of reducing excess supply in the UHF and VHF bands. The auction will continue until so many bidders have exited that all excess supply is eliminated and the FCC needs to accept the bids of all the non-exited bidders in order to meet its provisional clearing target. At the end of the auction, every bidder that has not exited will receive its last selected relinquishment option and be compensated according to the last accepted price offer for that option.

This auction has several attractive properties. First, it guarantees that two stations that broadcast in the same band with the same coverage area will receive identical price offers for all relinquishment options. Second, it asks only for the information it needs: no winning bidder reveals any information about how low it would have been willing to go. Third, it makes bidding well very simple. For a bidder that is considering only the option of going off-air rather than maintaining its UHF license, the hardest part of bidding will be to determine its value of continuing to broadcast. Once it knows that value, the rest is easy. The bidder cannot do better than to agree to accept any price greater than its value of continuing to broadcast and then to exit if its offered price falls lower than that. By bidding in this way, the station will obtain its best possible price for going off-air, and will not go off-air if that price is below the value it assigns to staying on-air. The auction is equally simple for a station that is deciding whether to continue UHF broadcasting or to exchange its license for a VHF license plus cash compensation. For this broadcaster, the hard problem is to determine how much value it would lose from switching bands. The optimal bidding strategy is equally easy: the station should remain in the auction unless the price it is offered for moving to VHF falls below this value. If the offered price does fall below this level, it should exit.

Bidding is easiest for broadcasters like those described that are considering just one option besides continuing to broadcast. A broadcaster that is considering multiple options, such as going off air, sharing with another bidder, or switching to a lower band, must track and evaluate multiple price offers and decide which one it considers best. But the bidder still has nothing to lose by participating: a bidder that

considers all of the price offers to be too low always has the option to reject them all, exit the auction, and be assigned a channel in its current band to continue broadcasting.

To make bidding easy for bidders, this auction proposal has been designed so that all the computational challenges fall on the FCC. Essentially, the computational problem for the FCC is to determine how much it can lower the prices it is offering to broadcasters, and in what order, while still getting enough “yesses” to meet its provisional clearing target. In order to do this, the FCC must calculate during the auction which stations are in “excess supply” in the sense that the provisional clearing target could be met without accepting the station’s bid, taking account of interference rules and treaty obligations with Canada and Mexico. At each round of the auction, the FCC will decrement the prices offered to bidders in excess supply, and rounds will continue until there are no stations in excess supply. The rules of the auction option described here also include a processing rule to determine which stations become winners if several stations decide to exit the auction or move bands in a given round, but the FCC cannot implement all of these changes together while meeting the provisional clearing target. The Reverse Auction section below contains more details.

Forward Auction: Bidding for new flexible use licenses

The main challenges for the Forward Auction arise from uncertainty about how many licenses will be available for sale and how they might be encumbered (which cannot be predicted with certainty before the Reverse Auction is complete), possible variations in the amount of bandwidth available in different areas, and the desire for a faster process compared to past FCC auctions. A faster Forward Auction is valuable because the outcome of the Reverse Auction cannot be determined until the nearly completed Forward Auction lets the FCC decide how much it can afford to pay to clear spectrum. Long delays in the Forward Auction could raise costs and discourage participation in the Reverse Auction.

Our primary option for the Forward Auction is an ascending clock auction that is an evolution of the FCC’s long-used SMR (“simultaneous multiple round”) design. The changes it incorporates should permit the auction to be completed in a fraction of the time that would be required by a traditional SMR auction, with no loss of efficiency or added difficulty for bidders. The three key changes are as follows:

1. *Licenses are generic.* During the main phase of the auction, bidders specify how much spectrum they want in a particular geographic area, e.g. 40 MHz (20 MHz uplink + 20 MHz downlink), rather than specific frequencies (e.g. blocks A, B, D, F). The auction winners are assigned specific frequencies in a separate “assignment phase” of the auction.
2. The design is a *clock auction*. At each round, the FCC announces prices for the licenses, raising the prices of the licenses that were in excess demand in the prior round. The bidders then state their demands, that is, the amount of spectrum in each area they wish to buy at the announced prices.

3. *There are no provisionally winning bidders designated at the end of each bidding round; intra-round bidding is used instead.* Intra-round bidding ensures that prices never increase so much that the number of units demanded for a type of license falls from above to below the available supply, leaving licenses unsold when there are willing buyers. Intra-round bids allow bidders to express the price points in the interval between the start-of-round and end-of-round prices at which they would change their demands and to specify how their demands would change.

This clock auction option reduces the number of rounds required for completion in two ways. First, compared to the SMR, it often compresses several rounds into one, since bids are for quantities rather than specific frequencies. For example, in an auction with four similar licenses and five bidders, an SMR can take four rounds of bidding for the prices of the four licenses to rise by one increment. In this clock auction option, the same price increase happens in a single round. Second, the clock auction with intra-round bidding permits the auctioneer to name larger prices increments without the danger of overshooting that an SMR auction with similar increments would suffer. The reason is that bidders in the clock auction are permitted to make bids at fractional increments. For example, a bidder can specify that when prices have increased by half of the auctioneer-specified increment, the bidder will reduce its demand or to switch demand from one product to another.

The clock auction also has the benefit that identical licenses will sell for the same price, something that is not guaranteed in the traditional SMR design.

Clearing Rule

Finally, designing an effective Clearing Rule that links the outcomes of the Forward and Reverse Auctions presents additional challenges. The Clearing Rule needs to ensure that the quantities of wireless broadband licenses to be sold in the Forward Auction correspond to what can be supplied using the broadcast licenses acquired in the Reverse Auction. This correspondence is more complicated for the Incentive Auction than for ordinary commodity auctions, on account of two factors. First, assuming the flexible spectrum is licensed in multiples of 5 MHz, the number of paired 5MHz wireless broadband licenses that can be created in any area is not strictly proportional to the number of unpaired 6MHz broadcast channels cleared. This non-proportionality is described in more detail in the next section. Second, the numbers of wireless broadband licenses available in different areas cannot be determined independently, both because some broadcasters' service areas may overlap several wireless broadband license areas and because there are benefits to having a consistent band plan across the nation.

To align bidding in the Forward and Reverse Auctions, the Clearing Rule sets a series of targets for the number of licenses to be sold in each region in the Forward Auction and for the number of UHF broadcast channels to be cleared. The Clearing Rule also sets Closing Conditions determining when the auctions can end based in part on the Net Revenue (the difference between the Forward Auction proceeds and the corresponding procurement cost in the Reverse Auction). The auctions begin with an initial provisional spectrum target that is set high, aiming to buy the rights necessary to achieve that target in a descending auction and to sell the corresponding flexible use (e.g., wireless broadband) licenses in an ascending auction. If running the Reverse and Forward Auctions with the initial provisional spectrum target satisfies the Closing Conditions, the Incentive Auction closes. Otherwise, the provisional spectrum target is reduced and the auctions continue.

The rest of this document describes these proposals and their logic in greater detail, beginning with a discussion of the conversion of channels into paired bands.

2. Converting Broadcast Spectrum to Wireless Spectrum

The Band Plan, which has not yet been finalized, will determine exactly which frequencies will be cleared in the Reverse Auction for each possible clearing target and the structure of the wireless licenses to be assigned in the Forward Auction.

In describing this auction design option, we will assume that the Reverse Auction will clear channels in the UHF band, while potentially moving UHF stations to the VHF band, and potentially having stations from any of these bands go off-air.

We also assume for any number of UHF channels cleared (above some minimum), it will be possible to create some number of paired (uplink and downlink) wireless licenses. We further assume that wireless licenses will cover Economic Areas (EAs), a geographic license unit used in a number of past FCC Spectrum Auctions. There may also be additional downlink-only licenses and some residual spectrum designated for unlicensed use.

The reason for having downlink only licenses as well as paired uplink and downlink licenses is that broadcast channels do not generally convert to whole numbers of paired wireless licenses. Broadcast channels are 6 MHz, while wireless licenses are often composed of 5 MHz blocks or multiples thereof. Spectrum also is needed to create guard bands that separate wireless broadband from neighboring spectrum uses. As a result, creating paired wireless licenses may leave “extra” spectrum to create supplementary downlink licenses, as well as “remainder” spectrum that will be part of the guard bands and may be available for unlicensed use.

Regional vs. National Band Plan. We assume in this auction design option that an attempt will be made to create a uniform national band plan, i.e., that the same channels will be cleared nationwide. However, it is possible that some exceptions will be required if broadcaster participation is too low in certain areas or Canadian or Mexican television allotments constrain the amount of spectrum that can be made available for flexible use. This may result in “impaired areas” where fewer licenses are offered in the forward auction.

3. Reverse Auction

Generally, the major rules of an auction can be described in terms of three elements: the bid collection procedure (how bid information is gathered from bidders), the assignment procedure (who gets what), and the pricing rule (how bids determine the prices). The Reverse Auction option we present here is a descending clock auction defined in the following general way. Bid information is gathered in a series of rounds in which stations are presented with price offers for different options for relinquishing rights (including going off-air or moving to a lower broadcast television band). Prices can fall but cannot rise from round to round. A bid for a station in each round specifies the broadcaster's preferred option for that station. Whenever the price offer for a broadcaster's currently preferred relinquishment option is reduced, that broadcaster is given the opportunity to exit the auction and continue broadcasting in its pre-auction band, and may also be given an opportunity to modify its preferred relinquishment option. Generally, the FCC's algorithm will decrement prices so as to reduce the excess supply of broadcasters willing to relinquish their rights and to make best use of the available broadcast channels. When the auction terminates, every broadcaster that has not exited will receive its last selected relinquishment option and be compensated according to its last accepted price offer for that option.

This description outlines the auction rules, but omits some algorithmic details. Final details will depend on how the FCC decides to measure interference and to determine what collections of broadcast stations can be fit into the remaining broadcast spectrum. To illustrate how the auction would work, consider a simple example. Imagine there are five stations with identical coverage areas currently assigned to channels. The goal is to clear three channels by paying two stations to go off-air. The auction starts by proposing to pay a high price to each station to go off-air. Some stations may choose to stay on-air, but assume that more than three offer to go off-air at that price. In subsequent rounds, the price for going off-air is decreased. As the proposed price falls, some stations that were willing to go off-air at a higher price will reject the lower price, instead choosing to stay on-air. When the number of stations assigned to go off-air is down to three, the auction is over: the stations staying on-air are assigned specific channels, and the stations going off-air are paid the current price.

The simple example abstracted from the facts that there are multiple bands (UHF and VHF) and that different stations have different coverage areas and create different interference for other stations. With multiple bands, a station may be offered a price not only for going off-air but also for accepting assignment to a lower band. Also, because the stations have different coverage areas and create different interference for other stations, the prices will be station-specific (although, as noted above, prices for two stations in the same band with the same coverage area would be the same). Furthermore, the number of channels to be cleared will not be fixed in advance, but may depend on the bids in the Forward Auction. Therefore, the Reverse Auction will begin by finding the prices at which a large number of channels can be cleared in every area and then, if necessary, will continue by finding the (lower) prices at which a smaller number of channels can be cleared.

Moving beyond the simple to a more general case, there are still multiple rounds of bidding. At the beginning of each round, there is a tentative assignment of stations to bands. Each station has a current offer price for going off-air, and for moving to a lower band, and is told whether these prices will decrease during the round. The station states whether it wants to stay in its currently assigned band, go off-air, or move to a lower band. The station may switch among these options, as prices decline. An activity rule enforces consistent bidding. The activity rule has the property that a station's decision to be assigned to its pre-auction band is irreversible: once made, the station "exits" the auction. Therefore, as in the simple example, the number of stations agreeing to go off-air or move to a lower band will decrease as the auction progresses.

In each round of the auction, a computer algorithm determines, for each station that has not exited, whether that station still could be assigned to its pre-auction band without violating the interference limits for the other stations already assigned to that band. When a station cannot be assigned a channel in its home band, it is "frozen" – its current assignment and the price for that assignment cannot be changed in this round. All the other prices may be decreased. For any station whose price for its currently preferred relinquishment option is decreased, the

station is invited to (a) change its preferred relinquishment option (in a way that may be restricted by an activity rule), (b) exit the auction, or (c) keep its preferred relinquishment option. At the end of the auction, every bidder that has not exited receives its last selected relinquishment option and is compensated according to the last price offer for this option. Bidders that have exited and stations that did not participate will be assigned specific channels in their pre-auction bands.

As described below, if there is insufficient demand in the Forward Auction at prices determined by the Reverse Auction, the FCC may reduce the provisional clearing target and the auction will continue. In that case, the assignments and prices of some stations will change. With a lower provisional clearing target, more stations will be able to be assigned channels in their pre-auction bands and prices paid to go off-air or move to a lower band will fall.

We now provide more details for this auction design option, starting with a few definitions.

Definitions

Permissible Bands. A station's Permissible Bands are the ones it potentially can choose during the auction.¹ For a station whose pre-auction band is UHF, the Permissible Bands are the UHF band and the upper VHF band. For a station currently in the upper VHF only the upper VHF band is permissible.

Provisional Clearing Target. The Provisional Clearing Target is the number of UHF broadcast channels to be cleared. The Provisional Clearing Target may be adjusted downward as the Reverse Auction proceeds. The same Provisional Clearing Target will apply nationally except in the event that broadcaster participation in certain regions is particularly low or Canadian or Mexican television allotments constrain the amount of spectrum that can be made available for flexible use. The FCC may then choose to designate certain geographic areas as Impaired Regions, and seek to clear a smaller number of channels in these areas.

Feasible Assignment. An assignment of stations to bands is *feasible* given a Clearing Target if every station under consideration can be given a channel in its assigned band in a way that satisfies FCC interference requirements.

Feasibility Checker. The auction computations will rely on a computer algorithm that can check whether any proposed assignment of stations to bands is a Feasible Assignment. The Feasibility Checker also will output a tentative assignment of stations to channels that meets the feasibility requirements. During the auction, the Feasibility Checker will be used repeatedly to determine whether, given a current Feasible Assignment, it would be possible to move a particular station to a different band and still have a Feasible Assignment.

¹ For simplicity of exposition we do not consider moves to the lower VHF band. The auction design can easily be extended to include moves to this band.

Active. A station that can feasibly be assigned to its pre-auction band, given the current assignments to other stations, is *active*.

Frozen. A station that cannot feasibly be assigned to its pre-auction band, given the current assignments of other stations, has its price *frozen* at the last price offer for its last selected relinquishment option (its *current tentative assignment*).

Exit. A station assigned to its pre-auction band has *exited* the auction.

Impaired regions. Wireless license areas in which less than the targeted amount of spectrum can be cleared at the reserve prices.

Description of the Auction

Initial Prices. Prior to the auction, the FCC will announce Initial Prices—the maximum prices the FCC will offer—for each station. A UHF broadcaster will see two prices: a price to go off-air and a price to move from UHF to upper VHF. An upper VHF broadcaster will see one price: a price to go off-air. The Initial Prices may be specified as a multiple of a station’s interference-free population coverage, and may vary by region or depending on a station’s home band. The Initial Price for going off-air will be greater than the Initial Price for moving to a lower band.

Initial Bids. In the initial round of the auction (Round 0), each station’s Initial Bid is a statement of its *preferred* relinquishment option (go off-air or move to another Permissible Band) at the relevant reserve prices, or alternatively to remain in its pre-auction band. Any station that does not participate will be assigned to its pre-auction band.

Initial Assignment. The FCC first will determine whether it is feasible to accept all Initial Bids, while assigning all non-participating stations in their home bands. If so, the Initial Clearing Target will be set equal to the maximum number of channels that can be cleared while accepting all the Initial Bids. During this process, certain regions may be designated as Impaired Regions and the number of channels cleared in these regions may be less than the Clearing Target. It also may happen that accepting all Initial Bids is not feasible for any Clearing Target. If this happens because of infeasibility in the VHF band (because too many stations’ Initial Bids select an assignment in that band), there will be an extra round in which VHF prices are decreased until enough stations choose to move out of this band to yield a Feasible Assignment, so that the initial Clearing Target can be set. This process generates a feasible Initial Assignment of stations to bands. Once a tentative Feasible Assignment is generated, a tentative Feasible Assignment will be maintained throughout the auction.

Determining Feasible Moves. Prior to each auction Round $t \geq 1$, and later during the bid processing for each Round, the FCC will use the Feasibility Checker to determine, for each station that is not currently assigned to its pre-auction band, which of its Permissible Bands the station could be feasibly reassigned to. A station that can feasibly be assigned to its pre-auction band, given the current auction assignments of other stations, is *active*. If a station *cannot* be feasibly assigned to its

pre-auction band, the station is *frozen*. Finally, if a station already is assigned to its pre-auction band, we say the station has *exited*. A station that has exited submits no further bids and is assigned a channel in its pre-auction band at the end of the auction.

Descending Station Prices. Prior to each Round $t \geq 1$, the FCC announces to each station that has not exited whether and by how much its offer prices will decrease in that round. A station may have just one or more of its prices decreased in a given round. Each station is also told its *current tentative assignment*, whether it is frozen or active, and if it is active, which relinquishment options for the station are feasible given the current tentative assignment. Stations also may be given additional information, for instance information about what fraction of channels are filled in UHF and VHF in the station's local area given the current assignment.

Bids. In each Round t , all stations that have neither exited nor been frozen are given the opportunity to modify their preferred relinquishment option or to exit.

Activity Rule. Bids will be required to satisfy an Activity Rule that ensures consistent bidding, so that for instance a station that chooses to go off-air rather than move to VHF may be prevented from making the reverse choice in the following round unless its price offer for going off-air is reduced by more than its price offer for moving to VHF. In particular, the Activity Rule will help prevent a station from choosing a band that is currently infeasible for it as its preferred relinquishment option, by reducing the prices for such bands by at least the same amount as the price for the station's current preferred relinquishment option. (The Activity Rule will never prevent a station from exiting in any round in which its price offer is reduced for its currently preferred relinquishment option.)

Intra-Round Bidding. In order to accelerate the auction without sacrificing efficiency, the following modified bid submission procedure may be used. Instead of a fixed reduction of prices for its relinquishment options, a bidder may be given end-of-round prices for these options that correspond to maximal possible reductions, and invited to submit one or more intra-round bids. Each intra-round bid specifies a price point in the interval between the start- and end-of-round prices in a Permissible Band or off-air at which he would like to modify his preferred option to another Permissible Band or off-air. For example, if the bidder's current preferred relinquishment option is the upper VHF band, he may specify a price point in this band that is between the start- and end-of-round prices. The bid might specify that when prices progress beyond the price point, the bidder's preferred relinquishment option should be modified to going off-air. The bidder might also make a second intra-round bid specifying a lower price point below which the bidder would prefer to exit the auction and remain in its pre-auction band. Within each round, a computer algorithm will process such intra-round bids sequentially, and decide which prices are decremented and by how much, and which intra-round bids are accepted as a result of the decrements.

Conditional Termination and Clearing Target Adjustment. The Reverse Auction continues until a point is reached at which every station is either frozen or has

exited the auction. The current assignment and prices then become the Conditional Outcome, which will become the Final Outcome if the closing conditions are satisfied. If the closing conditions are not satisfied, then the provisional Clearing Target will be decreased and additional assignments to UHF channels will become feasible so that some frozen stations may become active. The Reverse Auction then continues until again all stations are either frozen or have exited. This generates the Conditional Outcome for the new Clearing Target. Depending on the Clearing Rule for the overall auction, to be discussed in Section 5, the process continues.

Discussion

Bidder Incentives. The Reverse Auction is designed to provide stations with relatively straightforward bidding incentives. A single-station owner that considers *only* the possibility of going off-air, and not moving to a lower band, cannot do better for itself than to determine a minimal payment it would accept to relinquish its license, and then, during the auction, bid to go off-air until it cannot be assigned a channel in its pre-auction band or the offered price to go off-air falls below its minimal acceptable payment. Exiting earlier means foregoing an opportunity to be paid more than the station's minimal acceptable payment, while exiting later means getting paid less than its minimum acceptable amount.

There are no "strategic" elements to such a decision. The logic is analogous to a bidder seeking to buy a single item in an ascending clock auction: such a bidder should stay in the auction until the price reaches the bidder's maximum willingness to pay. In the Reverse Auction, the same logic also applies for a station that considers only the possibility of moving to upper VHF, or only moving to lower VHF, but not moving off-air. An important benefit of this approach is that it makes bidding simple and inexpensive for any broadcaster that chooses to participate in the auction.

For a bidder that is considering multiple options during the auction (e.g. potentially to go off-air or to move to VHF), a natural strategy is to choose the option that looks best given current prices. The auction does not guarantee absolutely that such a strategy will be optimal, but given competition among stations to relinquish their rights, the complexity of the interference constraints that determine feasible assignments, and the limited information that will be available to stations, the scope for such gaming is likely to be very limited. Similarly, for a bidder that owns multiple stations, the scope for gaming would be quite limited, provided that the bidder does not own a sizeable number of stations in any given local area.

Scoring Rule. The algorithm that determines how prices are decremented for each station in each round (and, in the intra-round bidding modification, which intra-round bids are accepted) is an important part of the auction design. This algorithm will rely on a "score" for each bid that accounts for factors like the potential interference created by a station and the population served by the station, as well as the money amount of the bid. The use of population in scoring could reflect the fact that the value of a broadcasting license depends in part on its

population served. Ranking bids and paying winning bidders in relation to their population served or other indicators of value may reduce the amount that the Commission would have to pay to repurpose broadcast television spectrum. The details of the scoring will need to be examined further.

Additional Possible Variations

Dynamic Maximum Prices. In the auction design option described above, the maximum price that can be paid to a broadcaster is the Initial Price in the auction. Setting the Initial Price well in this design is an important matter. If the FCC's choice of Initial Price were too low, the consequence would be to reduce the amount of spectrum that could be cleared in some areas. If it were too high, the consequence would be a higher cost of acquiring spectrum, which in turn could result in fewer channels being cleared. A variation to the design option that could mitigate the problem of setting Initial Prices that are either too high or too low would set the maximum prices (for example, on a per pop basis) paid to broadcasters dynamically during the auction. The *dynamic maximum prices* would be constructed using the bids in the early rounds of the auction. To implement this variation, the price decrement rules would be modified so that prices offered to bidders that exceed the corresponding dynamic maximum prices are reduced even when there is no excess supply. Just as after any reduction in the offered price, the bidder could reject its reduced price offer and exit to its pre-auction band, even when such exit might necessitate reducing the number of licenses that can be offered in a particular area in the forward auction. The potential advantage of dynamic maximum prices is that the maximum prices paid to broadcasters would be based on actual bids in the auction, rather than on the FCC's pre-auction price forecasts.

4. Forward Auction and Assignment

As previously noted, the major rules of an auction can be described in terms of three elements: the bid collection procedure (how bid information is gathered), the assignment procedure (who gets what), and the pricing rule (how bids determine the prices). Our Forward Auction option is an ascending clock auction, an evolution of the format used in past FCC auctions but with several novel features. The auction sells generic licenses, and takes the following general form. (1) There will be a series of rounds, with the FCC announcing prices in each round (the ascending prices are referred to as price "clocks") for each category of generic licenses in each geographic area, and bidders responding with the quantities of licenses of each type they seek at those prices. These quantities are restricted by certain detailed rules and in addition bidders are able to submit bids at intermediate prices. Generally, prices will rise in a round if there is excess demand for the product in the preceding round or if the closing conditions have not been satisfied. (2) When there is a round with no excess demand for any product, the closing conditions will be checked. (3) When the auction closes, winners pay the final clock prices for each product. Following the completion of the clock auction, there is a separate assignment phase to determine which particular frequencies are to be awarded to particular winners of generic

licenses, taking into account the importance of assigning contiguous frequencies to each winner.

Most importantly, the supply of licenses during the auction is not fixed for the entire auction, but may be adjusted as the Clearing Rule attempts to match demand and supply from the Forward and Reverse Auctions.

In addition, the auction design includes several features so that the auction can be run more quickly and in fewer rounds than past FCC auctions that sometimes have taken a month or more to complete. These features, which we describe below, include the use of “generic” licenses, “intra-round” bidding, and a “bid processing” rule that obviates the need to specify provisionally winning bids after rounds in which the aggregate demand for a product exceeds its supply.

For specificity in this Forward Auction design option, we assume that the Products offered for sale will include generic licenses for paired spectrum in each of the 176 Economic Areas (EAs). Generic licenses provide the right to a specific amount of spectrum in a specific area, but not to particular frequencies. The assignment to frequencies is done after the auction. The band plan may also include other Products, such as downlink-only licenses. From a band plan perspective, a key to making this auction run in significantly fewer rounds than an SMRA is that the generic licenses offered in a specific market should be generally “fungible.” That is to say, bidders should not care much about which specific frequencies they are assigned, but rather focus on “where” (geography) and “how much” (number of blocks). As described below, an “assignment round” will convert generic licenses into specific frequency assignments at the end of the auction. When discussing bids in the Forward Auction, “quantity” refers to a number of generic licenses.

The auction proceeds in a series of discrete rounds. At the outset of the auction, bidders express their demands for each Product at the reserve prices. Then, in each subsequent round, the FCC increases the prices of the Products where the Aggregate Demand (the total demand for that product by all bidders in the current round) exceeds the Supply. Bidders may then adjust their demands. This continues until no Products have excess demand, at which point the closing conditions specified by the Clearing Rule are checked. If the closing conditions are satisfied, the auction ends. Otherwise, prices continue to increase for each Product so long as demand for that Product is at least equal to the Supply, and the closing conditions are rechecked after each round. If they are met the auction closes. There may be several additional rounds of this kind until no further price increases are possible without leading to excess supply. At that time since the closing conditions cannot be met at the current provisional clearing target, the provisional target quantities are reduced as described by the Clearing Rule.

The process of price increases and demand adjustment, which we describe below, makes use of “intra-round” bids that are “processed” after each round of bidding. With intra-round bidding, the FCC announces a “start-of-round” price and an “end-of-round” price for each product with excess demand. Each bidder then states how it would like to change its demand as prices rise in this interval. The FCC

then processes the intra-round bids sequentially, starting with the lowest bids in the interval, allowing demand changes except when they would cause the Aggregate Demand for a Product to drop below its Supply and freezing the price of any Product in that round at the point where Aggregate Demand becomes equal to Supply. This prevents the auction price from “overshooting” and creating excess supply (resulting in unsold licenses where there had previously been demand for those licenses). As in the traditional FCC design, bidders also must satisfy an Activity Rule that requires them to bid actively in early rounds of the auction in order to maintain the ability to bid in later rounds of the auction.

We now provide a more detailed explanation of the rules.

Description of Rules

Supply. At the outset of the auction, and before each round, the FCC announces the available Supply of each Product.

Initial Prices. The initial prices are minimum prices set by the FCC. Traditionally, the FCC has specified initial prices in SMR auctions using a money amount multiplied by the population of the region associated with the license, sometimes with an adjustment for rural populations. Alternatively, it may use an econometric model to determine relative spectrum values and set the reserves in proportion to those values.

Initial Bids. A bid in the initial round of the auction (Round 0) states a quantity of each Product that the bidder is willing to purchase at the reserve price.

Price Increases. Prior to each Round $t \geq 1$, the FCC announces for each Product the amount by which its price may increase during the round. We refer to a Product's price before the increase as its “start-of-round” price, and its price after the increase as its “end-of-round” price. Prices are increased only for Products where the current Aggregate Demand exceeds the Supply. The size of the price increases may vary during the auction, for instance from 20% at the beginning of the auction to a smaller amount such as 5-10% in later rounds.

Intra-Round Bids. In each round, bidders may submit one or more “intra-round” bids. An intra-round bid specifies how a bidder would like to adjust its demand as prices increase toward their end-of-round levels. For example, a bidder could specify a demand decrease of 1 for Product A at a “price point” of 50%, meaning the bidder wants to reduce its demand for Product A by one unit when all prices have increased 50% of the way from start-of-round to end-of-round levels. Alternatively, or in addition, a bidder could specify a demand decrease of 1 for Product B and a demand increase of 1 for Product C at a price point of 75%. Such a bid would specify a switch of demand from Product B to C when prices have risen 75% of the way from start-of-round to end-of-round levels. An intra-round bid can involve multiple Products or units. A bidder can submit multiple intra-round bids within a round, but at most one bid at each price point.

The idea of intra-round bidding is to approximate a condition in which bidders can adjust their demands while prices rise almost continuously. Relative to the usual

FCC rules, it allows a shorter process by having fewer rounds with larger price increments from round to round, without the substantial loss of efficiency. The procedure also provides for a form of “tie-breaking” in case multiple bidders attempt to decrease their demands for a Product in a way that would lead to excess supply.

Activity Rule. The auction includes an Activity Rule similar to past FCC auctions. Before the auction, the FCC assigns each Product a number of points. Bidders also submit deposits that entitle them to a certain amount of bidding Eligibility. During the auction each bidder’s demand, measured in points, is limited by its Eligibility. A bidder’s Eligibility is updated after any demand adjustment and is set equal to the smaller of (1) its prior Eligibility or (2) the total number of points associated with its current demand divided by the Activity Requirement for that round. The FCC sets an initial Activity Requirement (say, 0.75), and may raise it during the auction.

Bid Restrictions. A bidder may not submit a bid that violates the Activity Rule, nor may a bid be withdrawn. In addition to the basic Activity Rule, there is also an “anti-stalling rule” that prohibits bidders from both increasing and decreasing demand for the same Product at different price points in the same round, or from increasing demand for a Product in a round where its price did not change and then reducing demand for the same Product in the next succeeding round.

Bid Processing. After intra-round bids are submitted, they are processed sequentially. The processing mimics what would happen if prices were raised continuously from their start-of-round to end-of-round levels. To achieve this, the intra-round bids are processed starting with the lowest price point and continuing upward. An intra-round bid is allowed so long as the requested demand adjustment(s) do not cause the Aggregate Demand for any Product to fall below the Supply of that Product. If an intra-round bid would cause “overshooting,” it is disallowed and the bidder is held at its prior demand. In this situation, it could happen that, later during the bid processing, another intra-round bid increases the Aggregate Demand for the relevant Product, and then the disallowed bid may be re-processed. The auction rules will contain a detailed description of this.

Posting of Prices. After the bids from Round t are processed, the FCC determines a posted price for each Product. For any Product that did not have a potential price increase in Round t (because Aggregate Demand was less than Supply), the Posted Price is set equal to the start-of-round price. For any Product where the Aggregate Demand after the round still exceeds the Supply, the Posted Price is set equal to the end-of-round price. Finally, for any Product where the Aggregate Demand fell to exactly the Supply, the Posted Price is set equal to the highest price at which the Aggregate Demand was adjusted down to this level (which could be 25% of the way from the start-of-round price, 73% of the way, etc.). For each Product, the posted price from Round t then becomes the start-of-round price for Round $t+1$.

Conditional Termination and Supply Adjustment. The Forward Auction continues until there is no excess demand for any Product. At that point, the FCC tests to see whether the closing conditions of the Clearing Rule are satisfied. If not, the prices

continue to increase for all licenses for which Aggregate Demand exceeds Supply until either the closing conditions are satisfied or no licenses remain for which Aggregate Demand exceeds Supply. If the closing conditions cannot be met, the provisional spectrum target is then adjusted as specified by the Clearing Rule and the auction continues. The exact adjustment will depend on the Band Plan, as discussed in the previous section.

Information Policy. Before each round, the start-of-round price, the end-of-round price and the Supply for each Product will be announced to each bidder. After each round, the Posted Price, the Aggregate Demand (evaluated using the processed demands for that round) and the bidder's own processed demand for each Product will be announced to each bidder. No other information about the bidding will be disclosed.

Residue. It may happen, after the auction, that some Products are in excess Supply. This could happen, for example, if certain Products never received sufficient demand. In this case, the final auction rules might call for the FCC to immediately re-auction these Additional Licenses or to hold them for later sale.

Assignment Stage. After completion of the Forward Auction, which determines the quantity of each Product allocated to each bidder, the Assignment Stage determines the actual frequencies to be assigned to each bidder in each EA based on the generic licenses won in the auction. The assignment stage ensures that each winning bidder obtains contiguous spectrum within each EA. If the only Product is paired spectrum, winning bidders will be allowed to choose "positions" based on a random priority ordering. If the Forward Auction also includes one or more blocks of downlink-only spectrum, this process can be modified so that at least one winner of downlink-only spectrum obtains this spectrum adjacent to any paired downlink spectrum it has won. The details of the Assignment Stage, however, will depend on the exact Band Plan.

Additional Possible Variations

The following additional possible variations are not currently included in our auction design option for the Forward Auction, but could be incorporated:

Self-Imposed Minimum Quantity. Before bidding begins, a bidder could be permitted to specify a minimum quantity of two units. If the bidder elects this option, it would only be allowed to demand two or more units of Product in any EA, or to demand no units of any Product in that EA. With this variation, an intra-round bid by this bidder that decreased its demand from two to zero and thereby brought the Aggregate Demand for the Product to one less than the Supply would be allowed. However, a bid that brought the Aggregate Demand for a Product to two units less than the Supply (or lower) would be rejected. We point out that, even without this rule, because the intra-round bids are processed as packages, a bidder can ensure that it never acquires a single unit, but can do so only at the cost of continuing to bid for two units as license prices rise.

Package Bidding. The current auction design option does not incorporate any explicit package bidding, although the intra-round bids are processed as package bids, mitigating the so-called “exposure problem,” according to which bidders may win some but not all of a set of complementary items. The Self-Imposed Minimum Quantity would expand package bidding in a limited way (allowing aggregations of at least two units in a given geographic area). An alternative approach would be to allow much more extensive packages, such as those of the combinatorial clock auctions (CCA) proposed for spectrum auctions in a number of European countries, Canada, and Australia, or certain limited packages, such as ones covering all EAs in a larger geographic grouping.

Alternative Activity Rules. The current auction design option includes a “points-based” activity rule that is similar to past FCC auctions. An alternative approach has been proposed for use in recent Combinatorial Clock Auctions, in which the activity rule permits bids if either they satisfy a 100% eligibility rule or if they satisfy a revealed-preference constraint with respect to prior bids.

Assignment Stage. The current auction design option includes a particular assignment procedure, in which winning bidders are randomly assigned priorities and then pick contiguous frequencies. An alternative approach would have winners of generic spectrum bid for the various positions.

5. Clearing Rule

The Clearing Rule specifies how the FCC will match demand and supply to determine the number of channels converted from broadcast to flexible use. Here we describe a general approach to the Clearing Rule. It is meant to be adaptable to a range of possible FCC decisions, including whether to conduct the Reverse Auction first, followed by the Forward Auction, or whether to interleave the two. The Clearing Rule incorporates a *Net Revenue* target that is some minimum amount because Section 6403(c)(2) of the *Spectrum Act* creates a minimum proceeds requirement for closure of the forward auction.

We first describe the Clearing Rule for a case in which the Reverse Auction is run first, followed by the Forward Auction, and in which the target number of channels to be cleared can only decrease during the Forward Auction. We then describe how to modify the rule so that the target number of channels cleared also can increase, and how to apply the Clearing Rule if the Reverse Auction and Forward Auction are run together in “interleaved” fashion.

Reverse Auction and Clearing Cost. The Reverse Auction determines the total amount that must be paid to broadcasters to achieve each Clearing Target of n channels (up to the maximum N). This is the Clearing Cost for n channels. As described above, the Reverse Auction may allow for variations in the numbers of licenses cleared in various EAs, so that when n channels are targeted for clearing, a smaller number of channels may be cleared in certain Impaired EAs.

Forward Auction Supply. The Forward Auction begins by setting Supply based on the Band Plan conversion of N channels (the maximum from the Reverse Auction) into wireless licenses. As the Forward Auction proceeds, the Supply may be adjusted to reflect the Band Plan conversion of a smaller number of channels, $n < N$.

Provisional Forward Auction Proceeds. At any point in the Forward Auction, the Provisional Proceeds associated with selling the current Supply may be computed as follows: for each license type, multiply the current price times the total number of that license type that would be sold (the minimum of the Supply and the Aggregate Demand) and sum across license types. We might also want to account for potential revenue from licenses that would be unsold, but that may be sold at a later date. To do so we could value each unsold license at some fraction of the current price of the same type of license.

Closing Conditions. The design will incorporate conditions that must be met for the auction to close. These conditions could require a minimum Net Revenue Target (Net Revenue is defined to be the difference between the Provisional Revenue from the Forward Auction and the corresponding procurement cost in the Reverse Auction), which would be at least sufficient to meet the statutory minimum proceeds requirement. A Closing Condition would be satisfied when the Net Revenue Target is reached or exceeded and there is no excess demand for any products. If the Net Revenue Target cannot be reached using the current provisional Clearing Target, then the provisional Clearing Target would be reduced by one channel and the Forward and Reverse auctions would continue. Additionally, the Closing Conditions could incorporate a trade-off between the amount of spectrum cleared and Net Revenue to ensure that the Commission does not give up too much spectrum clearing to attain slightly higher Net Revenue. If the increase in Net Revenue relative to the reduction in spectrum is too low, the auction would end at the previous (greater) Clearing Target. If the increase in Net Revenue relative to the reduction in spectrum is sufficiently large, the auction would continue with new, reduced Clearing Targets, until the clearing conditions are met.

Timing. The Clearing Rule we have described is consistent with two general approaches to auction timing. In one (the “Reverse Auction first” approach), the Reverse Auction is conducted for a series of provisional Clearing Targets before the Forward Auction begins. The second is a “staged” approach, in which the Forward and Reverse Auctions for n cleared channels could be conducted in parallel. If the Closing Conditions for n channels are not satisfied before the Forward Auction demand falls below the provisional Clearing Target, then the provisional Clearing Target is reduced and both auctions continue. This second approach requires close coordination between the two auctions, so that both can be run in the same time frame, but has the advantage that it requires bids only for the Clearing Targets that might actually be implemented. This staged approach preserves more privacy for bidders in both the Forward and Reverse Auctions than the Reverse Auction first approach.

6. Conclusion

In summary, the option presented above provides a comprehensive model of how an incentive auction might work in practice. We expect that this straw man can be adapted to serve the Commission's goals as it implements this new kind of auction.