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Report 2: Simultaneous Ascending Auctions with Package Bidding

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EXECUTIVE SUMMARY

An effective package bidding mechanism addresses three problems: the exposure problem (the risks a bidder faces in trying to construct an efficiently large combination of licenses), the free-rider problem (the difficulties small bidders have in beating those who bid for larger packages of licenses), and the computational complexity problem (which arises from the fact that the number of possible combinations of licenses is much larger than the number of licenses).

Package bidding offers the possibility of an improvement over individual-license bidding only when there are strong complementarities and the pattern of those complementarities varies across bidders. Package bidding works satisfactorily only when the auction rules have been carefully designed to manage all three problems.

I. Restrictions on Allowable Packages

Some restrictions on allowable packages are needed to limit the computational complexities. These restrictions should mirror the sources of complementarities, which can be based on (1) geography or (2) wavebands.

- **(1) Geographical License Structures**: For the geographical partition of licenses in the A and B Block PCS auctions, the United States was partitioned into 51 regions called MTAs (Major Trading Areas). Each MTA was, in turn, composed of many smaller units called BTAs (Basic Trading Areas). Complementarities among these licenses arise in two ways that could lead to two different kinds of package restrictions.

  – (1A) *Hierarchical structures*: Packages are restricted to consist of subsets of licenses such that, if any two subsets intersect, then one subset is entirely contained within the other. In the case of the AB Block auction, the individual licenses might be specified at the BTA level.

    Bidders would also be able to bid for a package of BTA licenses that covered an individual MTA. The FCC could further specify, say, five disjoint regions that coincide with collections of MTAs and allow bids for packages of licenses that cover those regions. Finally, a nationwide package of all licenses might be made available.

(1B) *Flexible package structures*: If bidders want to fill in licenses to complement incumbent holdings from previous license assignments to create a nationwide network, a rule that made all sufficiently large packages open for bidding would be workable. The rule could allow bidding for any package that covers 51 percent of the population (or for the package that covers all licenses for which the bidder is eligible). This gives flexibility to bidders in constructing packages than that is lacking in the hierarchical structure. A 51 percent minimum package size is chosen because it deters collusion and is computationally manageable.

- **(2) Complex Fitting Structures**: When several wavebands to be offered and different technologies require different combinations of the wavebands, the FCC could use its prior knowledge of the technologically determined complementarities to specify the allowed packages. As long there is a small number of items to be aggregated (i.e., wavebands), computational feasibility puts no limit on the number of packages that can be allowed.

II. Auction Rules

We take as our starting point the Simultaneous Ascending Auction (SAA) already used successfully by the FCC, and modify and extend it to introduce package bidding. Beyond restricting the set of allowed packages, the rules for the Simultaneous Ascending Auction with Package Bidding (SAAPB) include several features:

- **Assignment rule**: Suppose a number of different bid profiles have been submitted. Define a consistent collection to be a set of bids for packages that are not mutually exclusive but that exhaust the available licenses. The set of standing high bids at any time is that consistent collection with the highest total bid.

- **Bulletin board**: The auction will proceed in discrete rounds. Bids will be submitted to the bulletin board. The bulletin board has a dual role: to receive serious bids and to allow bidders to identify other bids with which they can combine into packages to supplant a current assignment. To ensure that the bulletin board is not cluttered with multiple non-serious bids, we propose various rules for acceptability for bids posted on the bulletin board. Unlike the rounds of bidding, which are discrete, the bulletin board will operate in continuous time, or as close to continuous time as is technologically feasible.

Report 2: Simultaneous Ascending Auctions with Package Bidding

- **Bidding discounts**: To avoid creating a strategic advantage for package bidders that might reduce both efficiency and revenue, we introduce bidding discounts for individual license bids. In the case of a 10 percent discount, a bid on an individual license of 100 would require the bidder to pay only 90, whereas a bid on a package of licenses of 100 would require full payment.

- **Minimum bid increments**: The original SAA rule required new bids to be at least x percent above the standing high bid. With package bidding, some modifications are necessary, setting minimum increments for new package assignments to supplant old package assignments.

- **Activity rules**: Bids on the bulletin board will earn activity credits only if they are translated into standing high bids. An activity rule similar to the SAA activity rule will govern the bidding.

- **Stopping rules**: The SAA employed an all-or-nothing stopping rule. As long as bidding remained active on any single license, all licenses remained open for possible bids from eligible bidders. This rule may be desirable for the SAAPB as well, though we also discuss the alternative of a license-by-license closing rule.

- **Withdrawal rules**: With the need to combine bids of various bidders to supplant standing assignments, it will be important to maintain significant penalties for withdrawals of standing high bids. Bidders who become part of a bidding consortium created by the bulletin board must be confident that their position is not vulnerable to withdrawals by other members of the consortium. Therefore, once a bid has been translated into a standing high bid, the bidder remains committed to ensuring that the FCC receives at least an amount equal to that bid for that license. Our recommendation is to prohibit withdrawals of package bids.

- **Waivers**: A liberal waiver policy may be required in the SAAPB in order to allow bidders the time to make fairly complex implicit negotiations in constructing bidding consortia and to give them the opportunity to respond to newly offered combinations of licenses.

- **Auction stages**: Stages should be used in the SAAPB just as in the SAA.

Report 2: Simultaneous Ascending Auctions with Package Bidding

III. Experimental Design

Modifying the FCC's SAA format to incorporate package bidding will represent a major change in a mechanism that has worked successfully. We propose a number of experimental tests (a) to establish under what conditions the SAAPB should be used instead of the SAA; and (b) to test the internal consistency of the proposed SAAPB rules and to compare certain options in the design of those rules.

The experiments should examine variations in the size of the complementarities and in the degree of heteregeneity of bidders' preferences. In addition, the experiments should examine the effects of varying the restrictions on package size, as well as the effects of bidding credits, alternative activity rules, and minimum bid increments.

1. INTRODUCTION

In our previous report (1B) we assessed alternative approaches to designing auction mechanisms that enable bidders to express complementarities in their valuations. We found that, under certain conditions, two particular mechanisms have theoretically attractive properties. In theory, a generalized Vickrey auction has desirable efficiency and incentive properties, resolving both the exposure problem and demand reduction problems that we described in our report. However, the Vickrey auction also suffers from important problems, including its reliance on price discrimination in favor of large bidders and the practical difficulties of implementing it for auctions for more than about 20 licenses. A simultaneous ascending auction with package bidding has somewhat weaker theoretical efficiency and incentive properties, but potentially provides bidders with greater information about common values, and is generally easier to implement.

This report continues the analysis of the simultaneous ascending auction with package bidding (SAAPB) mechanism and is intended to guide the design of experimental tests of package bidding mechanisms. In the remainder of this introduction we discuss the various objectives that must be balanced by a package bidding auction mechanism. In Section 2 we investigate how to use the geographic or technological context that characterizes the spectrum licenses to be auctioned to impose particular structures on the admissible license packages. In Section 3, after reviewing the major features of the simultaneous ascending auction, we describe how the simultaneous ascending format can be extended to packages of licenses. In Section 4 we outline the major procedural rules that are needed to implement an SAAPB. The effectiveness of many of the specific auction rules will not always be evident *a priori*. In Section 5, therefore, we

provide a series of recommendations for experimental testing of the environment and auction parameters to help evaluate the performance of the mechanism and calibrate some of its components.

The design of an effective and practical auction mechanism with package bidding involves minimizing the impact of three major problems: the exposure problem, the free-rider problem, and the computational complexity problem. In the following subsections we briefly describe each of these issues. In the remainder of this report, we show how the successful simultaneous ascending auction utilized by the FCC to sell spectrum rights can be modified in context-specific ways to minimize these problems.

1.1 The Exposure Problem

In Report 1B, we describe some of the reasons why a simultaneous ascending auction may fail to allow the market to reach an efficient assignment[1] of licenses to bidders. When bidders are permitted to bid only for single licenses, an exposure risk can arise. The valuation a bidder has for a group of licenses may far exceed the sum of the bidder's valuations for the individual licenses that make up the group; that is, the licenses may be strongly *complementary*. If a bidder seeking a particular group of complementary licenses eventually wins some — but not all — of the licenses in the group, those licenses might be worth much less to the bidder than their total price. Package bids enable a bidder to shelter himself from this risk since a bid for a package entails a commitment to pay only if all the licenses in the package are obtained.

1.2 The Free-Rider Problem

At the same time, package bidding creates the possibility of a free-rider problem for bidders seeking only individual licenses. The free-rider problem can allow a package bidder to win when efficiency dictates that the licenses not be aggregated. Imagine there are three bidders, E, W, and N, and two licenses, East and West. Firm E values owning East alone at $2 billion, West alone at $1 billion, and the nation (East and West together) at $3 billion. Firm W values East at $1 billion, West at $2 billion, and the nation at $3 billion. Firm N values East at $1.6 billion, West at $1.6 billion, and the nation at $3.3 billion. If nationwide bidding is not allowed, in the two open auctions (one for East, one for West), W wins West at a price slightly above $1.6 billion

[1] We follow the FCC's terminology in which spectrum bands are *allocated* to services and licenses in a band are *assigned* to individuals or firms.

(which is the price at which the second-highest bidder, who happens to be N, drops out), and E wins East at slightly above $1.6 billion. This is the ideal outcome since the licenses go to their highest-value users. Now suppose there is a national auction in addition to the two separate auctions. Anticipating winning the nationwide auction, N has no incentive to bid for the separate licenses. Only E and W bid for them, so the price of each stops at slightly more than $1 billion. However, all three bidders compete in the national auction. Firm N wins the nationwide bidding at slightly above $3 billion, which is where both E and W drop out. The nationwide bid exceeds the sum of the two separate bids. The upshot is that the outcome is inefficient. The nationwide bidder N wins and the auction revenues are reduced from $3.2 billion to $3.0 billion. This result is a consequence of a free-rider problem in that, while either E or W could raise their individual bids to beat N, each would prefer the other to bear the cost of doing so.

1.3 The Computational Complexity Problem

There is another problem constraining the use of package bidding. As the number of possible packages that bidders are allowed to bid on grows, the computational burden imposed on the mechanism and on the bidders grows even faster. For example, with only five regional licenses to sell, allowing all possible packages would require only 2^5 -1=31 packages. With 20 licenses, there are more than 1 million packages that need to be offered. With 102 MTA licenses for sale, this number exceeds 10^{30} — far higher than any realistic bound. In order to operate any auction with a significant number of licenses for sale, feasibility will require some limits on package bids.

2. AUCTION CONTEXT

Package bidding offers an improvement over individual license bidding when there are strong complementarities but the pattern of those complementarities varies across bidders. The only way to enable bidders to express preferences for all possible types of complementarities is to allow for an infeasibly large variety of package bids. The intractability of this option requires the auction designer to limit the types of packages for which bidders may bid.

Restrictions on allowable packages can be developed by examining the structure of preferences of the licensees who are expected to use the spectrum resource. Which restrictions on package bids limit bidders' relevant options the least will depend on the pattern of complementarities that are anticipated. In this section, we describe three canonical types of complementarities which we

believe have a high likelihood of arising and which offer guidance in developing principles for restricting the types of packages allowed in the auction.

2.1 Geographical License Structures

The geographical partition of licenses that characterized the A and B Block PCS auctions will serve as one of the focuses of our approach. In that auction, the United States was partitioned into 51 disjoint regions called MTAs (Major Trading Areas). Each MTA was, in turn, composed of many smaller units called BTAs (Basic Trading Areas). The AB Block auction also was partitioned across spectrum so that, within each MTA, the A license represented the right to use one 30MHz band of spectrum and the B license a different 30MHz band. The perception that bidders' preferences over licenses exhibited complementarities across geographic components and substitutability across spectrum components provides some guiding principles that can be exploited to limit the variety of package bids that may be offered in an auction with package bidding.

An important feature of the AB Block PCS auctions was the perception that it was possible to partition the licenses into groups such that all bidders viewed all licenses within the group as substitutes. Spectrum caps restricted every bidder to at most one license, either A or B, in any MTA, ensuring that the valuation of license B in an MTA to an owner of license A was always zero. Even in the absence of the spectrum caps, the 30 MHz bandwidth suggested there would be little likelihood of complementarities across the A and B licenses. Furthermore, it was also argued (with somewhat less strength) that, within an MTA, the A and B licenses were effectively homogeneous so that, for the same price, any bidder would be indifferent between acquiring either of the licenses. In this ideal scenario, the highly structured and common feature of these substitute licenses offer a natural way to simplify bids in simultaneous auctions. Bidders care only about whether they acquire a license within an MTA and not about the specific license band. Bids for licenses within a band, then, need only specify whether a license is desired; they do not need to specify a bid for each particular license.

A license for an MTA conferred the right to the exclusive use of certain parts of the spectrum in that MTA alone. The special nature of complementarities in this context is the presumption that the source of the complementarity is the same across bidders. In the case of the PCS auctions, these complementarities were thought to stem from geographic contiguity arising from economies of scale in marketing retail services, from the attraction of offering roaming capabilities to mobile phone customers travelling between proximate areas, or from more efficient spectrum use on the boundaries of contiguous licenses.

Report 2: Simultaneous Ascending Auctions with Package Bidding

Despite the substantial uniformity of preferences across bidders about the sources of complementarities, bidders in the AB Block auctions could and did differ over which particular aggregations of licenses generated the strongest complementary valuations. Furthermore, the complementarities may arise in two different ways that lead to two different approaches to package restrictions. The next subsections describe them in more detail and illustrate different approaches to restrictions on packages that arise from them.

2.1.1 HIERARCHICAL STRUCTURES

Most bidders in the FCC auctions are established companies that plan to integrate their business using the spectrum with other businesses or products. For example, in the PCS auctions, an LEC might seek to combine a new PCS service with its existing services to spread marketing and overhead costs, seeking a combination of licenses that covers its service area. In the same auction, an existing long-distance carrier might seek nationwide coverage to take full advantage of its existing customer base and to spread its development costs as widely as possible.

If the most important complementarities arise in these ways, then restrictions on packages that take the form of *hierarchical structures* may be desirable. These restrictions specify packages consisting of subsets of licenses with the feature that if any two subsets intersect, then one subset is entirely contained within the other. In the case of an auction like the AB (and C) Block auctions — let's call it the "Z-block" auction — the individual licenses might be specified at the BTA level. Bidders would also be able to bid for any of the packages of BTA licenses that covered an individual MTA. The FCC might also specify, say, five disjoint regions that coincide with collections of MTAs and allow bids for packages of licenses that cover those regions. Finally, a nationwide package of all licenses may be available. In this example, there are four levels of aggregation — individual BTAs, MTAs, Regions, and Nationwide. Additional levels are conceivable and, as will be illustrated later, are achievable at relatively low costs in computational complexity. The limitation of this approach, like any approach that restricts the set of allowed packages, is that it allows bidders to express complementarities in their bids only in the ways specified by the pre-established structure. Thus, if a bidder experiences complementarities from grouping licenses that serve, say, two regions, then it is forced to choose between bidding for the regions (or individual licenses or MTA packages) individually or bidding for the much larger nationwide package. Such a bidder is still subject to the exposure problem to some degree, depending on the extent of the complementarity between the two regional license packages.

2.1.2 FLEXIBLE PACKAGE STRUCTURES

An alternative structure may be desirable if bidders are attempting to fill in licenses to complement incumbent holdings from previous license assignments. This was the case, for example, for incumbent cellular license holders who sought PCS licenses to complement their network and establish nearly-national networks. In this case, a rule that made all sufficiently large packages open for bidding would be quite workable. To illustrate the idea, consider an auction like the AB auction in which all licenses provide the same spectrum bandwidth but have different population coverage. A possible rule for that setting would allow bidding for any package that covers 51 percent of the population, or for the package that covers all licenses for which the bidder is eligible.

The flexible structure with a rule for a minimum 51 percent package size simultaneously serves a number of different purposes. It offers bidders the opportunity to select any package size between 51 percent and 100 percent of the available coverage. It allows bidders a great amount of flexibility in expressing the sources of geographic complementarities. Thus, bidders with complementarities for licenses that span different regions could construct aggregations that reflect these complementarities, while at the same time, bidders with complementarities from licenses that cover some but not all of the same geographical area can offer a competing package structure; it will be up to the auction to determine which structure acquires the licenses. This approach has a significant advantage in flexibility over the hierarchical structure approach since the fungibility of the coverage limit allows bidders to construct their own optimal package of licenses.

Package limits above 50 percent also have valuable anti-collusion properties since no two package bidders can construct an acceptable pair of package bids. Furthermore, the lower the limit on package sizes, the larger the computational burden that is placed on the mechanism in determining feasible assignments. With a rule allowing packages covering less than 50 percent, numerous combinations of packages may have to be evaluated by the mechanism in assessing the most efficient assignment.

The drawback of the flexible structure approach is that the lower limit on package size prevents the bidders from expressing complementarities that arise from smaller packages. Of course, bidders will continue to have the option of constructing their own packages from individual licenses, but in doing so they may suffer an exposure risk. In environments where technological or industrial factors make it apparent that complementarities arise from much smaller aggregations, the FCC may consider utilizing a lower limit. Otherwise, we feel that a relatively large lower limit on package size is most appropriate.

2.2 Complex Fitting Structures

An alternative environment generating complementarities that offers guidance in how to restrict packages is the case of the complex fitting problems that arise for technological reasons. For example, suppose there are four contiguous equal-sized bands of spectrum — A, B, C, and D — for auction and that three alternative technologies could make use of these frequencies. Technology 1 uses a single band; technology 2 requires two contiguous bands; and technology 3 also requires two bands but with the further condition that the bands are separated by one band.

In this case, there are 11 possible groups of multiple licenses. But in addition to the four individual bands there are just four packages — (AB), (CD), (AC), and (BD) — that satisfy the requirements of the contending technologies in each geographic area. The first two packages satisfy the demands of technology 2 and the last two those of technology 3. As this example illustrates, in a complex fitting problem some of the relevant potential packages partially overlap each other, whereas in a hierarchical structure, if two packages intersect then one contains the other.

In the case of complex fitting structures, substantial *a priori* knowledge is required in order to anticipate the potential types of complementarities that may arise. However, as long as the number of items to be aggregated remains small, as in this example, computational feasibility may impose no serious limit on the number of package bids that are allowed.

3. GENERAL DESIGN PRINCIPLES

The package bidding auction design considered in this report is a modification of the simultaneous ascending auction (SAA) format employed by the FCC in previous auctions.

3.1 The Simultaneous Ascending Auction

The major features of the SAA are:

1) Multiple individual licenses are sold simultaneously;

2) The auction progresses through multiple, discrete rounds;

3) In each round, *eligible* bidders may submit *serious* bids for any license;

4) A *serious* bid for a license is any bid from an eligible bidder that exceeds the *standing high bid* for that license by a specified minimum increment;

5) At the end of each round, the highest bid for each license becomes the *standing high bid* for that license. If no bids are received, the previous standing high bid remains the standing high bid;

6) A bidder is *eligible* to bid for any collection of license if his *eligibility level* is greater than or equal to (a) the *activity weight* of licenses for which he is currently the high bidder plus (b) the activity weight of the new licenses in the collection of licenses he is bidding on in the current round;

7) The *activity weight* of a license is predetermined by the auction mechanism and is usually a function of the license characteristics, including population coverage and possibly bandwidth;

8) A bidder maintains activity levels from round to round by submitting serious bids or remaining high bidder on sufficient licenses;

9) The auction ends when no serious bids are received on any license;

10) The *pricing rule* is "pay-your-bid". Bidders with high bids on individual licenses when the auction ends acquire those licenses and are obliged to pay their bid.

The SAA format has been successful in allowing bidders the opportunity to pursue multiple, substitute licenses and to retarget their bidding goals as some licenses become too expensive. Evidence from the AB and C Block auctions suggest both that bidders were successful in creating valuable aggregations and that the degree of complementarities that these aggregations offered were fairly small.[2] In other environments, though, the SAA may be less successful in allowing bidders to pursue collections of licenses because such bidding strategies may force the bidders to incur the exposure risk described in Section 1.1. Seeking to acquire a combination of licenses and submitting bids based on the value to them of the combination, bidders may fail to acquire the complete grouping and be forced to pay a price far greater than the value of the incomplete bundle. Such an exposure problem is more serious the greater the degree of

[2] See Lawrence M. Ausubel, Peter Cramton, R. Preston McAfee, and John McMillan, "Synergies in Wireless Telephony: Evidence from the Broadband PCS Auctions," *Journal of Economics and Management Strategy* 6, Fall 1997, 497-527.

complementarity a single bidder enjoys from a group of licenses and the greater the likelihood that there are other bidders whose interest in portions of that group may frustrate his ability to acquire the entire package. This report addresses this weakness of the SAA by developing rules to allow package bidding in simultaneous ascending auctions.

3.2 Simultaneous Ascending Auction with Package Bidding (SAAPB)

The simultaneous characteristic of the SAA meant that, in any round, each bidder can be regarded as submitting a *profile* of bids $\{(a,b_a), (b,b_b), (c,b_c)...\}$. Each individual bid is a pair, where the bid (a,b_a) denotes that the bidder is making a bid in the amount b_a for license *a*, etc.

If we expand the SAA to allowing package bids then the concept of a bidders' profile is extended to $\{(A,b_A), (B,b_B), (C,b_C),..., (a,b_a), (b,b_b), (c,b_c)...\}$. An uppercase letter in the first component of a pair denotes a package of licenses and lowercase letters denote individual licenses. The number b_A denotes the price that the bidder is willing to pay for the package of licenses, *A*, but only if all licenses in that package are acquired. This extension requires that the SAA assignment rule be modified. It also must specify the nature of package bids that will be allowed and how packages constructed from individual bids can be encouraged. The remainder of this section addresses these extensions.

3.2.1 ASSIGNMENT RULE

License assignments in the SAA were very simple to compute because they could be determined on a license by license basis. Serious bids were assessed at the end of each round. The highest bid received for each license became the new standing high bid. If no serious bid was received for a license, the previous standing high bid remained the standing high bid. The assignment of licenses to the owners of the standing high bids represented a candidate assignment that would only change as new serious bids were received in later rounds.

In the SAAPB format, the assignment rule is more complicated because whether a license is assigned to one bidder may depend on the assignment of packages to other bidders. A collection of non-exclusive bids[3] $\Gamma=\{(A,b_A), (B,b_B), (C,b_C),..., (a,b_a), (b,b_b), (c,b_c)...\}$ (possibly but not

[3] Any two bids, *A* and *b*, in a collection (package or individual license) are non-exclusive if the assignment of one package or license according to its bid does not preclude assigning the other package or license according to its bid.

necessarily from a single bidder) is termed a *consistent collection* if the intersection of every pair of the subsets in the list *A,B,C,..,a,b,c,...* is empty.

Suppose a number of different bid profiles have been submitted. Out of these profiles, there will be a finite (though potentially large) number of consistent collections. For each consistent collection, Γ, the total revenue generated by that collection, TR(Γ) is computed by summing the bids for all the subsets of licenses in Γ. The consistent collection Γ*, which maximizes this total revenue, becomes the candidate assignment that any subsequent bid profiles must beat. We term this assignment the *standing assignment* and the corresponding bids for the licenses and/or packages, the *standing high (package) bids*. As in the SAA, the pricing rule for the SAAPB is pay-your-bid: if no new bids are received before the auction ends, licenses are allocated according to Γ* and the owners of the licenses are obligated to pay the amount they bid for each license or package of licenses. Observe that if all bidders submit bid profiles for individual licenses only, then this assignment rule yields the same assignment as the SAA.

3.2.2 PACKAGE BIDS

The determination of what package bids are to be allowed for a given environment should be the responsibility of the FCC in collaboration with its own engineers and industry participants and specialists. The case of package restrictions based on complex fitting problems is primarily a question of technology. Informed input is required to determine if fitting problems are relevant and, if so, what are the most likely package groupings. In the case of nested or hierarchical structures, the most salient questions concern whether additional levels of nesting are likely to offer much gain in terms of valuable aggregation opportunities and whether there is a strong likelihood that complementarities may arise *across* nested structures that make it difficult for bidders to construct their most preferred aggregations.

For example, a winner of the A block license in one MTA may prefer the A block over the B block in the adjacent MTA. Finally, if the flexible structure model is utilized, the greatest concern is whether the minimum package size fails to capture the most likely source of aggregation complementarities. In this case, we anticipate the largest risk to be the case where most complementarities come from economies of scale in the 35–50 percent range. The larger cases are already taken care of and smaller aggregations may be feasibly constructed by bidding for individual licenses.

package size, number of bids allowed, and contingent bids.

3.2.2.1 Restrictions on Package Size

As we noted in Report 1B, restrictions on the number of packages that may be bid for will typically be necessary both to reduce the scope for collusive agreements among bidders and to ensure the smooth operation of the auction design. The freedom to specify any division of licenses into groups offers bidders a particularly unambiguous way to signal their intentions and so to coordinate their bidding behavior, with the result that competition may be stifled. And the computing magnitude that arises when all possible combinations of licenses can be grouped into package bids can overwhelm a computerized auction.

In the case of complex fitting problems, the desirable package size should depend simply on the nature of the prior information about the possible sources of complementarities. Of course, computational feasibility may impose some limits on the variety of options that can be allowed. The general principle here is to allow all packages that may seriously form part of a valuable grouping. At the same time, the FCC must recognize that, in asking for input from industry about the nature of these packages, there may be an incentive for industry to suggest groupings that provide collusive benefits rather than optimally productive license use.

In the case of an auction like the AB Block auction, if the acceptable packages form a hierarchical structure, then the additional computational burden of package bidding is slight.

To illustrate, let us assume for now that the auction will be conducted entirely in discrete rounds. Suppose the BTAs are arranged into a K-level hierarchy. The lowest level, 1, is the set of the individual licenses and level K consists of just one package, which is the collection of all licenses. A package at any level k>1 can be duplicated by acquiring a set of smaller packages at level k-1. Formally, the packages at each level form a *partition* of all the BTA licenses. In the earlier example, we imagined that there are licenses covering BTAs at level 1, licenses covering MTAs at level 2, licenses covering five larger regions at level 3, and a license covering the entire nation at level 4. In this case, K = 4 and the number of packages at the first level is 493, at the second is 51, at the third is 5, and at the fourth is 1. Let us further elaborate the example by supposing that there are two licenses per BTA but bidders may acquire only one license per BTA and in each BTA the two licenses are homogeneous, so that they do not need to be bid for individually. Then, a bid profile for an individual bidder will consist of at most 550 (=493+51+5+1) bids.

For this structure, the algorithm computing the standing assignment proceeds in a series of comparisons beginning at level 1 and ending at level K. At level 1 (individual BTA licenses), the algorithm determines the two highest bids for the two available licenses. From the results for level 1, one may determine two synthetic bids for the two packages available in each MTA. The first is calculated by summing the highest bids at level 1 for each component BTA licenses, and the second is calculated by summing the second-highest bids. The algorithm then compares these synthetic bids with the actual MTA bids to determine the two highest bids at the MTA level. Let us call these the *highest bids at level 2*. The process at higher levels is just the same. From the highest bids at level 2, one determines two synthetic bids for level 3 and compares these with the actual bids at level 3 to determine the highest bids at level 3. The same calculation is performed at level 4 to determine the two highest bids for the nationwide package. Finally, the algorithm decomposes the winning synthetic bids into their constituent bids and marks each of those as a *standing high bid*. The sequential nature of the comparisons renders the computational problem very simple, because the comparisons in any one MTA (or region) are independent of assignments in other MTAs (or regions). This allows the computer algorithm to be run in negligible time, even in very large auctions, and permits even observers without computers to verify each calculation, giving the auction a valuable transparency.

In the case of flexible structures, the bidders themselves determine package size subject to the auction's minimum package size. With the 51 percent rule, bidders are free to determine any package size covering from 51 percent to 100 percent of the licenses available. This, too, can be computed very quickly, with one computation of a total price for all of the spectrum corresponding to each package bid and one more corresponding to no package bids. The highest bids in this case would be declared standing high bids, and the same calculation would be performed a second time with the remaining bids to determine the second group of standing high bids.

3.2.2.2 Restrictions on the Number of Package Bids that a Bidder May Submit

If the restriction on allowable packages does not *a priori* sufficiently limit the size of a bidder's bid profile, it may be necessary to fix an upper limit on the number of packages on which a bidder can bid in any given round. In the case of hierarchical structures, the nested computation of the optimal assignment will likely not require further restrictions on the number of bids that can be submitted for an auction the size of the AB Block auction. In complex fitting problems, there will generally be only a limited number of possible packages that are of interest, and as long as this is not a large number, no further restrictions may be needed.

If the flexible structures environment with the 51 percent minimal coverage restriction were applied to the AB Block auction, there would remain a potentially enormous number of possible packages. Some restrictions will therefore be needed.

In general, the mechanism will be more likely to generate successful bidding consortia the larger the number of packages that a bidder is allowed to submit. Thus, if a potential package bidder enjoys some complementarities but is relatively indifferent between packages $a \cup b \cup c$ and $b \cup c \cup d$, allowing the bidder to submit bids for both packages allows the possibility of matches with individual license bidders on either *a* or *d*. However, in order to prevent any one bidder from overloading the system with large bid profiles, it will be necessary to impose an upper bound on the number of packages requested. This bound should be fixed only by the computational capacity of the system.

Once the upper bound on the number of package bids is determined, say M, then the operation of the assignment algorithm for a flexible structure environment is straightforward, as described above. In this model, if there are n bidders and J spectrum bands each bidder can submit no more than M package bids, this yields at most $J \cdot (1+n \cdot M)$ assignments to evaluate.

3.2.2.3 Contingent and Mutually Exclusive Bids

The 1997 Balanced Budget Act[4] indicates Congress's desire to test "contingent" combinatorial bidding for spectrum resources. Package bidding auctions are intended to incorporate a variety of provisions for contingent bids. At the same time, allowing bidders unlimited freedom to specify contingent bids is both infeasible and undesirable on several grounds.

Contingencies expressed in a natural language pose two problems. First, a computerized auction mechanism cannot be programmed initially to anticipate all possible formulations of contingent demands of bidders. As we note in Report 1B, even allowing bidders to express contingencies through the full range of possible license combinations poses the auction designer with a problem that increases in size dramatically with the number of licenses. Second, natural language contingencies serve as an obvious channel for collusive communications and must be restricted if not banned.

[4] Section 3002(a) (1)(B)(i).

Report 2: Simultaneous Ascending Auctions with Package Bidding

For these reasons we recommend that package bidding auctions should not allow bids to be submitted with any contingencies that allow a bidder to condition his bid on the outcome of another bidder's success in the auction. Thus, a bid by bidder 1 on license group *A* should not be permitted to be contingent upon whether bidder 2 acquires licenses in group *B*.

Even with this restriction, the class of contingent bids will typically be too large and, therefore, further restrictions are required.

The extent to which an auction mechanism with package bidding allows bidders to engage in contingent bidding will depend on which bids in a profile of bids submitted by a bidder are treated as *mutually exclusive*. Suppose $\{(A,b_A), (B,b_B), (C,b_C),..., (a,b_a), (b,b_b), (c,b_c)...\}$ is a profile of bids submitted by a bidder where upper case letters denote a package of licenses and lower case letters denote individual licenses. The number b_A denotes the price that the bidder is willing to pay for the package of licenses, *A*, provided that all licenses in that package are acquired. However, the bidder may or may not be expressing a willingness to pay b_A in the event that he also wins other licenses. If all bids are mutually exclusive, then b_A is interpreted as a commitment to pay if and only if *A* is won. If all bids are non-exclusive, then it is interpreted as a commitment to pay if *A* is won independent of other events. The auction rules must specify under what conditions bids will be considered to be mutually exclusive. In general, the greater freedom bidders are granted to specify the mutually exclusive bids, the greater the computational complexity imposed on the mechanism.

We first remark that the SAAPB format already allows for a significant amount of mutually exclusive bidding. A package bid itself represents a form of contingent bid. For example, a bid for the package $a \cup b$ expresses the bidder's contingent desire for license *a* if and only if he acquires license *b*, and vice versa. Additional types of contingent bids occur when bidders can submit package bids with some mutually exclusive alternatives. For example, a bid of \$5 for *a* together with a contingent bid of \$12 for *b* if *a* is won is nearly equivalent to bids of \$5 for *a* and a mutually exclusive bid of \$17 for the package $a \cup b$. Similarly, a bid of \$5 for *A* and \$6 for *B* if *A* is not won is nearly equivalent to mutually exclusive bids of \$5 for *A* and \$6 for *B*.

The SAAPB license assignment rule implies that some bids in a profile must be treated as mutually exclusive. For any two bids in a profile, if the licenses that are asked for have a non-empty intersection, they must be treated as mutually exclusive. Thus, if license *a* is in the package of licenses, *A*, the bids (A,b_A) and (a,b_a) are mutually exclusive. Similarly, if *A* and *B* are overlapping packages of licenses, the bids for the two packages must be mutually exclusive. Note that, in an auction with flexible structure with a "51 percent restriction" on package size for

the case of geographical complementarities, any pair of package bids by a single bidder will be mutually exclusive.

In order to remain close to the spirit of the simultaneous ascending auction, it also seems preferable to treat all bids for individual licenses as non-exclusive. This feature continues to offer the market the opportunity to build aggregations smaller than those represented by the package bids although, as in the SAA, at the possible risk of exposure.

An additional sort of mutual exclusivity can be introduced by exploiting the substitutability of certain licenses. Consider the AB Block licenses without spectrum caps. A bidder who wishes one license in a given MTA, but not two, and is indifferent between the A or B license would prefer to submit mutually exclusive bids for the A license and for the B license. A bid profile that allows the bidder to specify whether he desires a license in a given geographic region accounts for this form of contingency. If bidders are not completely indifferent between the A and B licenses (for example, if an A block winner prefers to acquire the A block in an adjacent MTA) then winning bidders may be allowed to choose which of the licenses they wish to acquire. For example, if the final assignment yields a single MTA to each of two bidders, a natural rule would be to allow the higher bidder the first pick of the available bands.

Within these constraints, however, there remains a variety of possibilities for expressing contingent bids. We anticipate that the scope of allowable contingent bids will fall between two extremes. In the simplest regime, only bids for intersecting groups of licenses are considered mutually exclusive. This option offers the simplest variant on the original simultaneous ascending auction design and the operation of the assignment process is straightforward. In the most complex regime, bidders can identify which individual license bids are mutually exclusive with the package bids (but individual license bids remain non-mutually exclusive among themselves.)

The latter option might be considered if the flexible structure model is used since the computational complexity remains low. However, our belief is that the variety of contingencies that are available to bidders who can submit package bids and the mutual exclusivity for intersecting packages that is implied by the pricing already offer a great deal of flexibility. Furthermore, the strongest argument for allowing bidders to indicate mutual exclusivity across non-intersecting bids is to enable them to express preferences for multiple licenses without incurring the risk of winning too many licenses. The multiple-round feature of the auction alleviates some of this particular type of exposure risk. The moderate additional contingencies that are gained by the further degrees of mutual exclusivity do not seem to warrant the greater

computational costs that accompany them. As a result, our recommendation is to use the simplest option.

Since even this option includes the opportunity for some mutually exclusive bids, we need to decide what will be the consequences for measuring bidding activity. Certainly we do not want to add up the activity weights (i.e., points or pop coverage) of all mutually exclusive bids. Should the maximum points of the mutually exclusive bids be counted as bidding activity or an average or something else? We address this issue in Section 4.3.

3.2.3 THE BULLETIN BOARD

In Report 1B we suggested that a simultaneous ascending auction with package bidding could be implemented by adding to the SAA a second bidding channel — a *standby queue* — to which bidders could submit candidate package bids that were in themselves insufficient to displace the current standing high bids. Further analysis of this two-channel design suggests that we can realize the benefits of a standby queue more simply by establishing a single channel — the *bulletin board (BB)* — through which all bids will be received. During the course of the SAAPB, bidders will be able to read from the bulletin board the standing high bids and the standing assignment.

In the SAAPB the bulletin board has a dual role: to receive serious bids and to allow bidders to identify other bids with which they can combine into packages to supplant a current assignment. If the current assignment is generated by individual bids, then any new single bid, whether individual or package, that exceeds the prices on the standing high bids by the required bid increment will generate a new assignment. Therefore, the additional purpose of activity in the bulletin board will be to enable bidders to generate combinations of bids that will supplant a standing assignment that includes a package bid.

The bulletin board must embody three qualities. It must allow bidders to provide information about their willingness to attempt to supplant the current assignment. It must allow other bidders to obtain this information. And it must allow bidders enough time to engage in these activities.

3.2.3.1 Operation of the Bulletin Board

We envisage a bulletin board as operating in the following fashion. In order to offer bidders time to make decisions and in order to operate an activity rule similar to the original SAA, the

simultaneous ascending auction with package bids will progress through a sequence of discrete bidding rounds in a manner similar to the simultaneous ascending auction. Throughout a round, standing high bids determine a candidate assignment. If the auction were to end in that round, this is the assignment of licenses that will result. We term this the *standing assignment* and the bids that underlie it the *standing high bids*.

Observe that a standing assignment may consist of both package bids and individual bids. Individual license bids in a standing assignment may be overbid by a single bidder bidding for an individual license or for a package. Package bids may be overbid by another package. However, for an individual license bidder to supplant a package bid, bids from other bidders will usually be required. It is this need to construct such supplanting bidding consortia that the bulletin board is intended to address.

Over the duration of each round, bidders may submit bids that, if they are accepted but are insufficient to be new standing high bids, are posted on the publicly observable bulletin board. Other bidders may use these bids in an attempt to construct a new assignment that dominates the revenues generated by the standing assignment.

When a bid is submitted to the BB it is first checked to ensure that it is an *acceptable bid.* If the bid is accepted, it is then tested against the standing assignment to determine if the bid, in combination with other standing high bids and/or bids posted on the BB, results in an increase in total revenue. If so, and if the bidder has sufficient eligibility for this bid, it becomes part of the new standing assignment. The new standing assignment is announced immediately and the bids making up the standing assignment are posted. If the new bid is accepted but does not displace the standing assignment it is posted as a *tentative bid* on the BB.

The requirement for accepting a tentative bid that does not automatically supplant a standing high bid is that that it must offer the possibility of a new standing assignment. The intent of this restriction is to prevent bidders from using the bulletin board to communicate to other bidders by submitting very low bids. Such bids are costless to the bidder because they have little chance of actually winning. They offer little value to the auction mechanism and could be used to generate collusive communications.

Although the definition of an acceptable bid may vary with the context, we offer a description of how the rule would work in the case of geographical license structures. If the bid, in combination with already-posted tentative bids and/or standing high bids, is sufficient to supplant a standing high package bid plus the required increment, then it is acceptable. Otherwise, first compute a

valuation index for the standing package bid that the new bid is attempting to supplant. We anticipate this would be simply an average per-pop price of the package computed by dividing the standing high bid for the package plus the required increment by the total population covered by the package. Then compute the average per-pop price of the combination of the new bid and already-accepted tentative bids. If this average price exceeds the valuation index of the package bid, then the new bid is acceptable.

The drawback of this rule is that if licenses within a package are heterogeneous in their sources of value, then computing the average price per pop across a package may impose an unwarrantedly high tentative bid for some licenses. This rule places the onus on bidders interested in high-value licenses to initiate a consortium of individual bidders to supplant a standing high package bid. A lower-value bidder can then join the consortium without meeting the minimum bid requirement if its bid is sufficient to complete a package that displaces the current assignment.

Bids that are translated into standing high bids are counted toward bidding activity.

3.2.3.2 Implementation of the Bulletin Board

The mechanism we have described is one of "continuous, real-time" bidding during a round — bids that are submitted are evaluated at once, and if they supplant the current assignment immediately become new standing high bids. Of course, communication between a bidder and the auction administrator requires some time, and evaluating submitted bids and calculating the optimal assignment is not instantaneous. There will necessarily be some time lag between submission of a new bid, posting of new standing high bids, and receipt of the new information by bidders. It may, therefore, be practical to divide a round into short, discrete intervals and to post updates at the end of each interval.

3.2.3.4 Amount of Information Provided

As we noted in our previous report, a "dark" queue where bidders submit bid profiles but are not able to observe the bid profiles of other bidders may reduce the chances that the queue is used for collusive bidding. However, unless bidders are able to identify potential combinations that will supplant the current assignment, the process of using the queue is nothing more than throwing a collection of tentative bids into the pot in the hopes that one of the bids hits a lucky combination. We feel that allowing bidders to observe other bids on the queue will increase the likelihood that

bidders will identify potentially profitable combinations and seek to create them by submitting their own complementary bids.

This process may be further encouraged by the mechanism itself. At the end of the preceding round, the standing assignment and the corresponding bids will be made public. It will also be useful to make public the next-closest T ranked assignments (ranked by total revenues) that would be generated by tentative bids on the BB on the presumption that these groupings may provide the best chance for topping the candidate assignment. Similarly, as a bid profile is submitted to the bulletin board, if it does not immediately become part of a standing high bid, the mechanism should report the top T assignments that would currently be generated by the bulletin board.

As soon as an acceptable tentative bid for a subset of a standing high package bid is received, the minimum average per-pop bid for the complement of licenses in the standing high package bid that would be required to beat the package bid should be calculated and posted to the bulletin board.

3.2.3.4 Anonymity of Bidders

There seems to be little reason to identify bidders who have submitted tentative bids to the bulletin board, and making such information available would likely increase the opportunity for collusion. The one concern that might arise stems from the experience of the nationwide narrowband licenses. In that auction, bidders were not identified; nevertheless, many participants were able to recognize who submitted which bids. If some bidders are more successful than others at such identification, suppressing the identity of bidders may introduce a distortionary asymmetry among bidders.

It may also be desirable to uncouple bid profiles. All bids in a profile that are not mutually exclusive may be made public as if separate bids, with no identifier indicating that they belong to the same bidder. However, mutually exclusive bids should be linked so that bidders can use that information in attempting to generate a new consortium.

4. PROCEDURAL RULES FOR THE SAAPB

We are now in a position to examine how the major procedural rules of the SAA should be modified and extended to account for package bidding. In the following sections we outline the

principal considerations that should govern the rules for bidding discounts, minimum bid increments, bidding activity, eligibility and auction stages, withdrawal of bids, waivers, and stopping.

4.1 Discounts for Individual Bids and Small Packages

Report 1B illustrated the possibility that individual bidders may be unwilling to bear the burden of increasing their bids sufficiently to oust a standing high package bid, with the result that efficient individual bids fail to win the licenses. This "free rider" problem creates a bias toward package bids that may need to be addressed. We suggest using discounts for individual license bids. For example, with a 10 percent discount, a bid on an individual license of (*a*,100) would be counted as a bid of 100 for individual license *a* but would obligate the bidder to pay only 90, whereas any package bid of (*A*,100) obligates the bidder to pay the full 100 for package *A*.

We further suggest that once a bidder has submitted a package bid, then any subsequent bid by that bidder for any individual license within that package would be ineligible for the individual license bidding discounts. This rule is intended to discourage the use of package bids in earlier stages of the auction, since such a bid reduces the options available to a bidder as the auction progresses. We believe that it is generally desirable for the auction to activate package bidding only in the latter stages, since it is only when the licenses approach their final prices that bidders will be subject to the exposure risk. Only then will a bidder wish to use package bids to reduce this risk. Earlier in the auction package bids have the possibility of serving as market division instruments — instruments that should be discouraged. Furthermore, the more bids on individual licenses that are available, the greater the pricing information that is dispersed to the bidding market.

The rule may impose a cost if the complementarities are highly discontinuous and unbalanced. In this case a bidder may be prevented from expressing his true valuations through the bids. For example, suppose that bidder 1 values license *a* at 105 on its own, *b* at 0 on its own, and the pair at 200 and has submitted a package bid for the pair. With bidding discounts of 10 percent, individual bidders can bid 110 (and pay only 99) for each license and supplant bidder 1's package bid of 200. Furthermore, the package bidder's sincere bid of 105 for license *a* will be insufficient to overcome an individual license bid for *a* with the bidding discount even though the package bidder may value it up to 10 percent more.

In an auction with hierarchical structure one could also use differential bidder discounts. Consider the example with four levels to the structure: BTA, MTA, Regional, and Nationwide. If

a free-rider problem is perceived to exist on all levels, then the spirit of using bid discounts suggests using them differentially at each level. Thus, for example, individual bids could acquire a bid discount of 15 percent, MTA bids a discount of 10 percent, and Regional bids a discount of 5 percent. The objective of simplicity, of course, serves as a counter-argument to this option. Unless there is a strong perception that free-rider problems are present on all levels, we suggest using just a single discount. In the example above, our sense is that if a bid discount is applied equally and only to BTA and MTA bids, it would be sufficient to address much of the strategic problem that arises from the free-rider issue.

4.2 Minimum Bid Increments

The original SAA rule limiting bids on individual licenses to be at least the maximum of x percent above the standing high bid and a specified dollar amount per point does not need to be changed. However, with package bidding and the bulletin board, some modifications are necessary for other types of bids. Minimum improvement levels should be set for new assignments to supplant old assignments. The 5 percent rule that predominated in the earlier FCC auctions seems appropriate here; however, care must be taken in determining how it is to be applied. Consider a candidate new assignment and compare it to the standing assignment. If the new assignment were to become the standing assignment, some licenses would have new high bids; let the collection of those licenses be X and let T_X be the total of the old standing high bids on the licenses, X. In order for the new assignment to supplant the old assignment, the revenue raised on X (taking bidding discounts into account) by the new assignment must exceed T_X by a minimum x percent.

This rule has some desirable implications. Package bids that contain any combination of the packages and individual licenses in the standing high assignment must exceed the sum of the standing high bids for the licenses in that package by at least 5 percent. Similarly, individual license bids must exceed the standing high bid for that license by at least 5 percent if the standing assignment includes an individual license bid for that license.

4.3 Eligibility and Activity Rules

Throughout the simultaneous ascending auction with package bidding, a bidder is constrained in the bids he may make by his eligibility. A bidder's initial eligibility to bid for licenses is determined by the funds he deposits with the FCC. During the auction, the bidder's activity is measured in terms of the activity points assigned to individual licenses. Bidders earn activity

credits equal to the sum of the activity weights of the licenses for which they hold serious bids. A bidder's eligibility in each round is determined by his bidding activity in the previous round. In each stage of the auction the bidder is restricted not to bid on more licenses than allowed by his current eligibility.

Activity rules encourage bidders to submit serious bids early and often. Bidders are not eligible to submit bids on licenses that exceeded their eligibility level. Eligibility can be maintained only with serious bids on licenses with sufficient activity, or by exercising one of the limited number of activity rule waivers granted to bidders. Bidders earned activity credits equal to the sum of the activity weights of the licenses for which they had serious bids — i.e., licenses on which they submitted new serious bids or other licenses for which they held the standing high bid from the preceding round.[5]

If an individual license bid exceeds the standing high bid on an individual license by at least the minimum-bid increment, then it is a serious bid. If a package bid that contains a standing high package bid (and possibly additional individual license bids) exceeds the sum of the standing high bids on those licenses by at least the minimum-bid increment, then that bid is a serious bid. In both cases, activity credits are earned on the basis of a predetermined rule (such as the population coverage of the licenses).[6] [7]

[5] Activity weight can be assigned to an individual license according to a proxy measure of the value of the license. For example, population coverage and bandwidth have been used to assign activity weights. A more general approach is to use a point system to assign points from a relatively small series of integers to each license; this has been implemented in other auctions. Rather than assigning weights in strict proportion to population, a point system can be designed to provide greater switching flexibility for bidders (particularly in later rounds), and the auction designer can give less-than-proportionate weight to very large markets in order encourage substitution among licenses and greater competition for the largest markets. For illustrative purposes, however, we will generally use "per-pop" measures of activity.

[6] In the Mexico SAA auctions, activity was calculated via points, not pops. Each license is allocated a certain number of points, which was roughly but not exactly proportional to pops. Points reduce the integer problems that activity rules can generate and that can impede bidders switching across licenses. If the largest property on offer is assigned, say, 60 points, then other properties can be assigned points that are divisors of 60 in such a way that many combinations of properties add up to any given points total (and therefore satisfy a given activity requirement). For simplicity of presentation, in this report we assume that population coverage is used to determine the activity weight of a license but the rules presented here are easily adapted to the more flexible point system.

[7] Note that this approach offers the opportunity to parameterize the mechanism by varying the required bid increment. For example, the simplest rule would require that all bids exceed the standing high bid by the same bid increment of 5 percent. A slightly more complicated rule would require a bid increment of 5 percent for the first acceptable bid on a license but only 2 percent for subsequent bids to be acceptable within the current round.

If a true continuous-time bidding round is infeasible, bids will be submitted and evaluated in a sequence of short sub-rounds. In this case, we recommend no change in the bid evaluation rules: bids are processed according to their time stamp as if all processing were instantaneous.

The fact that bids may be submitted, beaten, and resubmitted within a round requires that detailed provision be made for the activity levels of an active bidder within a round. We have already ruled that bidders acquire bidding activity only if they are the owner of a standing high bid within a round. The following situations could arise: (i) What if a bidder owns a standing high bid on some license or licenses, *A*, early in the round, is beaten on *A*, and then retakes it? In this case, it seems clear that the bidder's activity level from this behavior should simply reflect a single serious bid on *A*. (ii) More problematically, what if, rather than retaking *A*, the bidder now targets a new package or individual license, *B*? Should the bidder gain activity credit for *A*, for *B*, or for *A* and *B*? (iii) What if the bidder submits a serious bid on *A* and *B* but loses *B* later in the round? Should activity credits be applied only to *A*?

We suggest that the following rule appears to be most consistent with the activity rule in the SAA and should be applied here: Each bidder gets activity credit for those licenses on which it is active in a round.

In the original SAA a bidder was not eligible to submit bids on licenses with activity weights that exceeded his eligibility level. In the SAAPB the corresponding rule is that the consistent collection of tentative and standing high bids submitted by a bidder may not exceed the bidder's current eligibility level. Thus a bidder may submit a tentative bid that is mutually exclusive with a standing high bid that he owns without exceeding his eligibility.

In the SAA the level of activity required to maintain eligibility is increased in each successive stage of the auction. The same rule can be used in the SAAPB to relate a bidder's next-round's eligibility to this-round's activity level .

4.4 Stopping Rules

The SAA employed an all-or-nothing stopping rule. As long as bidding remained active on any single license, all licenses remained open for possible bids from eligible bidders. This rule may be desirable for the SAAPB as well.

(continued)

In Report 1A, we suggested the alternative of a license-by-license closing rule. This option may limit the possibilities for collusive behavior as the knowledge that certain licenses have closed may destroy the mechanism for self-supporting market sharing arrangements. On the other hand, it would also reduce the possibility of developing socially profitable bidding consortia as the auction progresses. The adoption of this alternative stopping rule in conjunction with the other changes we've recommended could confound the comparison of package bidding with the original SAA rules. For that reason, we do not recommend its adoption at this time.

4.5 Withdrawal Rules

Bids may be withdrawn from the bulletin board as long as they have not been successfully combined into standing high bids.

It will be important to maintain significant costs for withdrawals of standing high bids. Bidders who become part of a bidding consortium created by the bulletin board must be confident that their position is not vulnerable to withdrawals by other members of the consortium. Therefore, once a bid has been translated into a standing high bid, the owner of that bid remains committed to ensuring that the FCC receives at least an amount equal to that bid for that license. In the event of a withdrawal on an individual license, the current assignment of all other licenses remains the same and the withdrawing bidder is responsible to pay the maximum of zero and the difference between the withdrawn bid and the final sale price of that license. This rule is similar to the original withdrawal rule.

Withdrawals of package bids are far more problematic since there may never be another request for precisely the package that is withdrawn. One option is to make the withdrawing bidder responsible for the maximum of zero and the difference between the withdrawn bid and the final sale price of the licenses in the package using an average per-pop price for licenses that ended up being sold in an overlapping package and the actual price for the remaining individual licenses. This solution is problematic if individual license bids are offered bidding discounts and if there is significant variation in per-pop values of licenses in the final winning package.

Our preferred alternative is simply to prohibit withdrawals of package bids and to back the prohibition with very severe sanctions. The primary purpose of providing a withdrawal option in the SAA was to reduce the exposure risk by enabling bidders who failed to gain the desired aggregation to back out of the rest of the licenses. Now that we are using package bids, this purpose has become less important. Once again, this rule may be the focus of experimental

testing. We anticipate that there will be little loss in efficiency from prohibiting withdrawals and the gain in the simplicity of the mechanism and speed of the auction will be substantial.

4.6 Waivers

A liberal waiver policy may be required in this mechanism in order to allow bidders the time to make fairly complex implicit negotiations in constructing bidding consortia and to give them the opportunity to respond to newly offered combinations of licenses. This is particularly important if rounds are short, but less important if rounds are long.

4.7 Auction Stages

The introduction of package bidding does not seem to require significant modification of the use of stages in the auction. However, the fact that eligibility may become more complicated with the operation of the bulletin board might argue for limiting the use of stages on grounds of simplicity.

5. EXPERIMENTAL DESIGN

Modifying the FCC's SAA format to incorporate any type of package bidding will represent a major change in a mechanism that has now been successfully applied in a sizeable number of auctions. The FCC will want to be well informed and to proceed very carefully when altering the current format. By use of independent experimental testing in laboratories unrelated to the individuals advocating the different mechanisms, the FCC can obtain information about key auction parameters and candidate rules for a package auction design. Independent laboratory tests may also yield insights into package bidding mechanisms that are not yet anticipated.

Three important goals can be achieved through experimental testing of the SAAPB format. First, the performance of the mechanism should be assessed. Second, the sensitivity of this performance to changes in the environment should be determined. Third, the effectiveness of various instrumental parameters of the mechanism should be evaluated. In this section, we offer a description of the dimensions along which the SAAPB format may be tested experimentally. Since it is unlikely that all possible variations can be tested, the FCC will wish to decide which elements of these tests are the most important.

Report 2: Simultaneous Ascending Auctions with Package Bidding

5.1 Assessing the Performance of the SAAPB

The FCC's success with the SAA format and the fact that the SAAPB represents a direct modification of the SAA both suggest that an important comparison in any experimental test of package bidding should be of how the SAAPB performs relative to the original format. In order to achieve this latter comparison, any experiment should consist of parallel testing of the original SAA format and the modified SAAPB. Performance ratios should allow us to assess both the overall efficiency of the new mechanism and provide information about the ability of the mechanism to address weaknesses in the original format.

5.2 Varying the Environment

5.2.1 VARYING THE SOURCES OF COMPLEMENTARITIES

The SAA performs well in a context where bidders' preferences for licenses exhibit only substitutability and no complementarities. It is helpful, therefore, to use environments of this type as the starting point for assessing the performance of the SAAPB. From simple contexts of this type, the most important control is to vary bidders' preferences to allow for different types of complementarities. In keeping with the contexts that were used to restrict package bids, environments that could be introduced are those with complex fitting problems, where bidders have competing aggregation goals; hierarchical structures, where complementarities are continuously increasing in the size of the package; and flexible structures, where bidders continue to enjoy complementarities through economies of scale but differ among each other in terms of the types of aggregations that yield these complementarities.

Along with this range of bidder preferences, a variety of other modifications will be important to understand the robustness of the SAAPB.

5.2.2 HETEROGENEOUS BIDDERS

It is unlikely that bidders' preferences will fall uniformly within the contexts that we have identified in this report. In particular, in any auction, we can expect that many individual-license bidders will be present as well as bidders interested in aggregations of licenses. An experimental control should allow us to discover how sensitive the performance of the mechanism is in the presence of only package license-bidders as well as a combination of package- and individual-license bidders.

5.2.3 COLLUSIVE STRUCTURES

It is important that the SAAPB discourage collusive bidding. While the primary responsibility to prevent collusion should remain the domain of the Department of Justice, the ability of bidders in various environments to divide implicitly the market in an SAAPB should be tested. We stress that it is not always evident how to acquire this information experimentally. Nevertheless, certain controls might be envisaged. One such control could be simply providing a small lecture at the start of some experiments describing to bidders the principle of implicit collusion and the various strategic ways it is applied. This is meant to reflect the reality of the discussions and seminars among bidders and consultants that have followed the conclusion of some FCC auctions. Another would be to distribute preferences over licenses in such a way that the motivation for collusive agreements is exaggerated.

5.3 Varying the Mechanism Parameters

The SAAPB as described in this report offers significant flexibility that allows the auctioneer to tailor it to specific contexts. Experimental testing of this flexibility can be useful in learning how sensitive outcomes are to changes in the mechanism.

5.3.1 PACKAGE SIZE

The most evident mechanism control variable is the restrictions on package size. With the different sources of complementarities, it will be valuable to learn how sensitive the performance of the mechanism is to misspecifications of packages. For example, how will the SAAPB perform if the hierarchical structure system is used when the underlying preferences are geographic but not hierarchical? In the flexible structures model, experimental outcomes may be used to assess the efficiency costs of imposing a high lower limit on package size when the true source of complementarities stems from a smaller-sized package.

5.3.2 ANTI-COLLUSION INSTRUMENTS

The SAAPB has been designed to include various instruments to discourage collusive bidding. With an effective control that will encourage collusive motivations, we can also determine the effectiveness of these instruments. For example, license-by-license closing rules and the 51 percent minimal package size in the flexible structures model serve anti-collusion purposes.

They also impose potential efficiency costs. Experimental variation can be used to assess the sizes of the benefits and costs separately. The impact of other instruments such as the amount of information provided through the bulletin board may also be evaluated.

5.3.3 BIDDING DISCOUNTS

Auctions with package bidding induce a free-rider problem when both package bidders and individual bidders are present. The use of bidding discounts have been introduced in the SAAPB as a novel way to address this strategic concern. Experiments can help to determine whether such discounts work as intended, and the size of discounts that are required.

5.3.4 ACTIVITY RULES

The SAAPB restricts the initial tentative bids that can be placed on the bulletin board to be high enough so that the average per-pop price exceeds the per-pop price of the standing package bid. This was to ensure that the bulletin board is used only to construct supplanting consortium bids. Experimental variation of this rule can be used to test its effectiveness and to see if lower bids are ever used to construct supplanting consortia.

5.3.5 MINIMUM BID INCREMENTS

Since multiple standing high bids may be received within the same bidding round, it may be useful to assess the impact of varying the required bid increments depending on when the bid is received. For example, one rule could require all serious bids to exceed the current standing high bid by the same increment. Another rule may be to impose lower bid increments in the given round after the first serious bid supplants the original standing high bid.

Report 2: Simultaneous Ascending Auctions with Package Bidding

GLOSSARY

Acceptable bids	Bids which are high enough to offer the possibility of supplanting a standing high allocation and which, therefore, will be allowed to be posted on the bulletin board.
Allocation	Spectrum bands are allocated to technologies.
Assignment	Licenses are assigned to bidders.
Bid profile	A profile of bids is $\{(A,b_A), (B,b_B), (C,b_C),..., (a,b_a), (b,b_b), (c,b_c)...\}$ where an uppercase letter denotes a package of licenses and lowercase letters denote individual licenses. The number b_A denotes the price that the bidder is willing to pay for the package of licenses, *A*, only if all licenses in that package are acquired.
Collection or combination	A set of one or more individual licenses, and/or one or more packages of individual licenses.
Consistent collection	A collection of non-exclusive bids $\Gamma=\{(A,b_A), (B,b_B), (C,b_C),..., (a,b_a), (b,b_b), (c,b_c)...\}$ (possibly but not necessarily from a single bidder) is termed *consistent* if the intersection of any two of the subsets in the list *A,B,C,..,a,b,c,...* is empty.
Contingent bid	A bid placed by a bidder on a license or a package of licenses that is effective only when some other event occurs such as the bidder winning on one or more other specified licenses or packages on which he has placed a bid.
Mutual exclusivity	A bid for a license that is intended to be a commitment only if other licenses (the mutually exclusive licenses) are not won.
Non-exclusive	A commitment to pay for an individual license or a package of licenses independent of whether or not any other licenses are won.

Report 2: Simultaneous Ascending Auctions with Package Bidding

Standing (high) assignment	The assignment that is the consistent collection yielding the highest revenue.
Standing high bids	The bids for the licenses and/or packages corresponding to (contained in) the standing high assignment.
Tentative bids	A valid bid submitted to the bulletin board that is not sufficient to displace a standing high bid.