An Experimental Analysis of the Federal Communications Commission's Eligibility Rules

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By

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Executive Summary

The Simultaneous Multiple Round ("SMR") auction employed by the Federal Communications Commission ("FCC") may contain several rules that unnecessarily complicate the task of assessing the comparative performance characteristics of the SMR and the "combinatorial" auction provided under Task #1. The present study uses economic experiments to examine the effect that two distinct yet interrelated rules have on the performance of the SMR auction. The first rule assigns unequal eligibility points to different licenses, and the second rule controls the amount of flexibility that the bidder maintains during the course of the auction for a given level of bidding activity. These two rules are collectively referred to herein as the Eligibility Rule.

The two-part structure of the current rule suggested the evaluation of the alternatives listed in the table below:

Alternative Eligibility Rules

	Nonflexible	**Flexible**
Equal	Baseline	Flexible Eligibility
Unequal	License Differentiation	Flexible Eligibility & License Differentiation

Experiments were conducted to examine the performance properties of all four Eligibility Rules. Because the results of an experiment may be sensitive to the bidder valuation environment within which it is conducted, experiments were run under four different bidder valuation environments: (1) additive; (2) low superadditivity; (3) medium superadditivity; and (4) high superadditivity. A variety of measures were used to evaluate auction performance, the most important of which were assignment efficiency, revenue, and auction length.

The results of the experiments indicate that there is no statistically significant difference in the performance properties of the four alternative eligibility rules when the value a bidder places on any set of licenses is "additive" (equal to the sum of the values of the individual licenses that comprise the set). Moreover, a statistical analysis determined that none of the Eligibility Rules have a statistically significant effect on auction revenue under such a bidder valuation environment. In addition to these standard auction performance measurements, a statistical analysis was conducted to determine whether the alternative Eligibility Rules were equal in their effect on the level of bidder losses that occurred under an additive valuation environment. This analysis reveals that there is no statistically significant difference among the alternative eligibility forms in regards to bidder losses. Under all four Eligibility Rules bidder losses were either zero or negligible.

Analyses were also conducted to examine whether there are statistically significant differences in the performance properties of the four different Eligibility Rules when the value any bidder places on a set of licenses is superadditive (greater than the sum of the values of the individual licenses that comprise the set). They reveal that the increased flexibility in eligibility has a positive effect on assignment efficiency. Moreover, the analyses reveal that assignment efficiency is not affected by whether licenses are assigned unequal or equal points, and is also independent of the level of superadditivity in the valuation that bidders place on a set of licenses.

The analyses additionally reveal that flexible eligibility and the assignment of equal eligibility points across all licenses have significant positive effects on auction revenue. The analyses also find that an increase in the average size of the package of licenses that generate superadditive value also increases auction revenue. While the adoption of flexible eligibility enhances revenue by 3%, the analyses also indicate that such a rule increases the average auction length by 20%.

1.0 Introduction

The Federal Communications Commission ("FCC") has assigned Cybernomics Inc. the task of comparing the performance properties of the auction it currently uses to assign radio spectrum licenses (herein referred to as the Simultaneous Multiple Round ("SMR") auction), and a new auction form in which bidders are able to submit bids for single licenses as well as bids for combinations of such licenses (a so-called "combinatorial" auction). The SMR auction may contain several rules that may unnecessarily complicate the task of completing the comparative performance evaluation. Such a complication may arise if one or more rules have little or no effect on the performance properties of the auction. The present study examines whether two distinct, yet inter-related, rules that comprise the *bidder eligibility rule* have such an effect. If the eligibility rules have an effect on auction performance, the conducted analysis will determine whether this effect is positive or negative. If the economic experiments demonstrate that the existing eligibility rules have either zero or a negative effect on the performance of the SMR auction, they will not be included in the tested SMR mechanism.

2.0 Unequal Eligibility Points and Tapered Eligibility

A market institution consists, in part, of a set of explicit rules that govern the behavior of the market participants. Because of the complexity of the expected bidding environment and the potential for strategic behavior on the part of participants, the SMR auction employed by the FCC includes numerous rules. The large bidding strategy space made possible by the expected bidding environment makes it difficult for existing economic theory to provide anything more than a broad guideline on the likely effect of a given rule on the performance of the SMR auction. This research analyzes the effects of two SMR auction rules– the rule that assigns unequal eligibility points to different licenses, and the rule that tapers the amount of eligibility that the bidder maintains during the course of the auction for a given level of bidding activity.

2.1 Eligibility Rules

The FCC employs a Simultaneous Multi-Round (SMR) ascending bid auction to assign radio spectrum licenses. Under such an auction, participants submit single-item bids for individual spectrum licenses. Once the bids are submitted, a simple algorithm identifies the current high bids and the current high bidders. Participants have the opportunity to raise their bids in subsequent rounds. The auction is a "simultaneous" auction in that all licenses are put up for sale concurrently and that the individual auctions for the separate licenses all close at the same time. The simultaneous and iterative nature of the SMR auction raises the issue of how best to control the speed with which the auction progresses. It is possible that in some of the spectrum auctions bidders benefit from knowing their rivals' bidding strategies and license value estimates. Consequently, bidders may have the incentive to limit their bidding activity and simply observe their rivals' bids. To address this concern, the FCC adopted "eligibility rules." These rules encourage bidding by limiting a bidder's ability to bid on licenses in subsequent bidding rounds if he fails to maintain a certain level of bidding activity in the previous round.

The value used to establish a bidder's minimum bidding activity for purposes of maintaining a given level of bidding eligibility is defined in terms of the product of the amount of spectrum assigned to a given license and the total population within the license service area. This so-called "MHz-POPs " value for each license is assigned a number of *eligibility points*. A bidder maintains eligibility points for bidding in subsequent rounds by owning the current high bid on a license, or submitting an "improving" bid that is equal to the current high bid plus some specified bid increment. Because a bidder's eligibility points determine his bidding flexibility, a bidder should assign an "option value" to the maintenance of such points.

Believing that bidders may need substantial bidding flexibility in the early rounds of the auction, the FCC employs a multiple stage, tapered eligibility rule. Each stage is defined according to the number of eligibility points bidders obtain when bidding on a particular license times a scalar greater than 1[1]. Recognizing that some of the bidding activity may be motivated by strategic considerations, the FCC attempts to restrict bidding flexibility in later rounds. It accomplishes this goal by successively reducing the scalar from stage to stage. Each successive reduction in the scalar factor imposes a more stringent bidding constraint on the bidder. For example, a reduction in the scalar factor from 1.5 to 1.0 effectively reduces by one-third the number of eligibility points a bidder can maintain by bidding on a particular license.

Bykowsky and Cull (1998) note that the inequality in the number of eligibility points derived from bidding on spectrum licenses means that, for a given bidder, the size of the option value derived from bidding on a license: (1) differs across licenses[2]; and (2) increases as the eligibility tapers. The inequality in option value across licenses may result in artificially high prices for licenses with "low" population (e.g., low eligibility points) and a less efficient license assignment. This result would occur if bidders were incapable of maintaining sufficient bidding flexibility in later rounds to be able to bid on and possibly acquire licenses that cover "large" populations. Milgrom(1998) coined the term eligibility "parking" to describe a strategy in which bidders disguise true value for certain licenses by bidding on other licenses which are not as profitable at current auction prices. For whatever strategic reason a bidder may wish to do so, inequality in eligibility points may make the adoption of a "hide in the weeds" strategy more difficult. This increase in difficulty may enhance efficiency by reducing the opportunities bidders have to engage in such strategic behavior.

Eligibility management has been identified as a major strategic concern of spectrum auction participants (see Salant (1995)). By increasing a bidder's ability to maintain flexibility, Flexible eligibility may enhance assignment efficiency relative to a strict, point for point, eligibility rule. Moreover, Flexible eligibility may be most effective in the presence of unequal eligibility points across licenses which increase the difficulty

[1] For example, if the scalar is 3 in a given round, and the bidder submits a bid on a license that has 10 eligibility points associated with it, then in the next round the bidder has the flexibility to submit bids on licenses that total up to 30 points, or the current round's total eligibility, whichever is less.

in managing eligibility. However Flexible eligibility may grant an excessive amount of bidding flexibility to participants and, in so doing, prolong the length of the auction.

3.0 Experimental Design and Protocols

This section describes in detail the four different eligibility rules used to run the SMR experiments, the protocols employed to train subjects, subject payoff incentives, methods for dealing with individual bankruptcy, subject recruitment, the nature of the licenses auctioned, and the structure of the valuations possessed by bidders.

3.1 Auction Rules

In these SMR experiments ten licenses were offered for sale. The licenses were generically labeled A, B, C, ..., J. Participants submitted a series of single-item, sealed bids for desired licenses. Following the submission of such bids, the high bid for each license is posted. These high bids then become the standing bids for the next round of bidding. In addition to these general rules, we adopted the following specific rules:

0. *Activity:* In order to be able to submit a bid in a round, a participant must have submitted an acceptable bid in the previous round or have had a standing bid two rounds previous.

1. *Acceptable bids:* In order for a bid to be *acceptable* in any round, it must be greater, by a pre-specified increment, than the standing bid for that license.

2. *Bid increments:* The minimum acceptable bid for a license in the next round is the current standing bid plus a fixed percentage of that standing bid. The fixed percentage is determined by the excess bids placed on the license. Specifically, if one bid was submitted on the license the minimum acceptable bid would be (1+.05)*(standing bid); if two bids were submitted on the license then the minimum acceptable bid would be (1+.10)*(standing bid); if three or more bids

[2] The number of eligibility points assigned to licenses may also vary because of differences in the amount of spectrum associated with the licenses.

were submitted on the license then the minimum acceptable bid would be (1+.15)*(standing bid).[3]

3. *Bid Withdrawal:* Subjects are allowed to *withdraw* any of their standing bids before a round begins. After a withdrawal, the FCC becomes the standing bidder for the withdrawn license and replaces the bid with one that is less than or equal to the withdrawn bid. An individual who withdraws a bid pays a <u>*penalty*</u> equal to the maximum of zero or the difference between the amount of the bid he withdrew and the highest bid submitted by a participant other than the FCC after his withdrawal.[4] In the past, the FCC did not limit the number of withdrawals a participant could use. With concurrence from the FCC, we used a limit of 2 rounds of withdrawals per subject.[5]

4. *Eligibility:* Each license has, associated with it, a fixed number of eligibility points. A participant is constrained to bid for at most a subset S of licenses, other than the ones she has the current standing bid on, that satisfies the following eligibility constraint:

   $(\sum_{i \in S} \text{Points}_i) \leq$ (the sum of the eligibility points of licenses for which the participant submitted acceptable bids in the previous round and does not currently have the standing bid + the sum of the eligibility points of licenses for which the participant had the standing bid 2 rounds previous but no longer has the standing bid)

5. *Stopping rule:* The auction stops when all bidders have no eligibility remaining beyond their standing bids. The items are awarded to the participants with the standing bids and any withdrawal penalties are paid at that time.

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[3] We imposed what the FCC refers to as "click-box" bidding. This form of bidding allows the bidder to only increase its bid in integer multiples of the identified increment. Thus, if the increment amount were 10% for a particular license, any bid submitted for that license was restricted to be Standing Bid * (1 + π*.10), where π is a positive integer greater than or equal to 1.

[4] Because a standing bid on a license may be withdrawn multiple times, the highest bid after a withdrawal need not be the final bid on a license.

[5] Also, with agreement from the FCC, we combined the bidding and withdrawal phases of the auction. While this speeds up the auction, it does create an uncertainty on the part of the withdrawing party who cannot signal the availability of a license before bidding begins.

In a departure from the currently used SMR auction, the tested SMR auction did not include *bid waivers* and an *up-front deposit* rule. A *waiver* allows a bidder to extend to the next subsequent bidding round its current level of bidding eligibility without bidding in the current round. A bidder may desire such flexibility in response to either a computer hardware or software problem, or due to an unexpected need to consult with senior management on bidding or financing matters. However, given that these situations were not part of the experimental environment, a waiver rule was not a necessary element of the tested SMR auction.[6]

The SMR auction also requires that a participant make a "significant" *upfront deposit*. The *upfront deposit* determines the maximum number of eligibility points a bidder can attempt to acquire in any given round. Since we did not impose budget constraints on participants in the experimental environment, there was no need for initial deposits. Instead, we simply allowed each bidder to be eligible to bid on all licenses in the first round.

3.2 Treatment Variables and Structure

An experimental analysis includes varying an environmental condition or institutional rule and observing the effect of this variation on outcomes. The varied factor is defined as the *treatment variable*. The present analysis included two institutional treatment variables described below.

3.2.1 Flexible Versus Nonflexible Eligibility

The first treatment variable took on two discrete values: Flexible and Nonflexible. In the SMR auction a scalar $\omega \geq 1$ is selected which constrains a participant to bid for at most a subset S of licenses, excluding the licenses for which she has the highest standing bid, that satisfies the constraint:

[6] The decision not to include such a rule was approved by the FCC prior to conducting the experiments.

$(\sum_{i \in S} \text{Points}_i) \leq \omega \bullet$ (the sum of the eligibility points of licenses for which the participant submitted acceptable bids in the previous round and does not currently have the standing bid + the sum of the eligibility points of licenses for which the participant had the standing bid 2 rounds previous but no longer has the standing bid)

The Flexible treatment set $\omega = 1.5$ and the Nonflexible treatment set $\omega = 1$ for all bidding rounds.[7]

3.2.2 Unequal Versus Equal License Eligibility Points

The second treatment variable also took on two discrete values: Unequal and Equal. In the Unequal treatment each license was assigned a specific number of eligibility points based upon the size of its population: the larger the population covered by the license, the higher the number of eligibility points assigned to the license. Population was strongly correlated with the value of the license. Table 3.2.2 shows the assignment of eligibility points for each license in the Unequal condition:

Table 3.2.2 License Eligibility Point Assignments

License	A	B	C	D	E	F	G	H	I	J
Points	1	2	3	4	5	1	2	3	4	5

In the Equal treatment each license was assigned exactly1 point, regardless of the size of its population (value).

3.2.3 The Structure of Treatment Variables

Given that each treatment variable takes on two values, there are four different rule treatment combinations. Table 3.2.3 below presents these four combinations:

[7] The tapered SMR auction uses *stages* to gradually restrict the number of licenses on which a participant can bid. Let j = 1,2…M denote the stage of the auction. For each stage there is a number $\omega_j \geq 1$ such that $\omega_1 > \omega_2 > \ldots > \omega_M$. We did not use any stages in order to isolate the effect of the increased flexibility in tapered auctions.

Table 3.2.3 2 x 2 Experimental Treatments

	Nonflexible	**Flexible**
Equal	Baseline	Flexible Eligibility
Unequal	Point Differentiation	Flexible Eligibility & Point Differentiation

Experiments comparing the four different eligibility rule treatments will permit an examination of the potential tradeoff between, for example, greater assignment efficiency and prolonged auction length.

3.3 Market Demand

The effect of a particular eligibility rule treatment on observed outcomes may depend upon the bidding environment. The bidding environment is characterized by the level of superadditivity among license values, whether or not a competitive equilibrium exists, and the difference in values between the highest and second highest valuations, among other factors.

3.3.1 Valuation Structure

Economic theory (Bykowsky, Cull, and Ledyard (1999)) and past experiments (see Ledyard, Porter and Rangel (1998)) suggest that the SMR auction should have little problem in generating efficient allocations when bidder valuations are additive.[8] In such an environment, the SMR auction should produce a set of prices and a license allocation that closely approximate the results obtained under competitive equilibrium conditions. However, problems may arise when bidder valuations exhibit superadditivities or synergies (we will use these terms synonymously for the remainder of this document).[9]

[8] For any subset of licenses L, the total value of the subset for subject i is the sum of his individual values: $V^i(L) = \Sigma_{j\in L}\ V^i{}_j$.

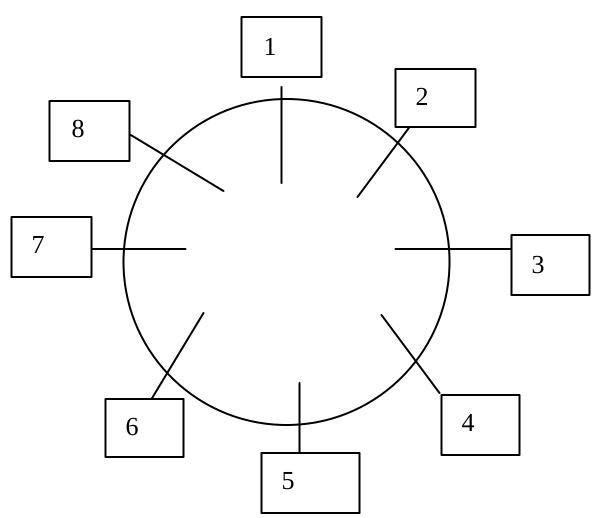
[9] We ignore the subadditivite case because of limited resources to investigate it. Resource permitting, at a later date we will examine the case in which bidders are budget constrained which has similar effect.

Subject i's valuation ($V^i(X)$) for a subset of licenses (X) is parameterized by the following expression:

$$\mathbf{V^i(X) = \Sigma_{j \in X} V^i_j + \lambda^i (\Sigma_{j \in X}\, \theta)^{\beta i} + \Delta^i (\Sigma_{j \in X} \Sigma_{k \in \cup A^j}\, \delta^j(k))^{\alpha i}}$$

The first term represents the sum of the stand-alone values of the licenses in the subset L.[10] The next two terms were added to model two potential license value superadditivities. The first term captures a scale economy a bidder achieves when using, for instance, its existing billing service and maintenance departments with the new service.[11] The reduction in the average total service cost per customer introduces a superadditivity in a bidder’s license valuations for a given set of licenses. The second term attempts to capture license value superadditivity that results from the value a mobile service subscriber places on being able to roam seamlessly from one service area to another. Due to this effect, some bidders may experience a superadditivity in license valuation across a set of contiguous licenses. To represent this type of value superadditivity, consider the topology of licenses described in Figure 3.3.1 below. Each point on the wheel represents a license and a geographical location. Licenses adjacent to each other (e.g., license {1, 2} and {8,1}) are considered contiguous.

Figure 3.3.1



[10] We correlated these values with the number of eligibility points associated with each license.
[11] This structure is somewhat similar to the econometric model developed by Ausubel et al. (1997).

If we let δ^j denote a zero/one indicator function for license j, then we can describe the contiguity relationship as follows:

$$\delta^j(k) = \begin{cases} 1 & \text{if } k = +/-1 \ j \bmod n; \\ 0 & \text{otherwise.} \end{cases}$$

Experiments were conducted under four different valuation environments: (1) additive; (2) low superadditivity; (3) medium superadditivity; and (4) high superadditivity. The four environments were generated by varying the parameters, λ, β, Δ, and α, the separate increases in which lead to an increase in the degree of license value superadditivity.[12] Table 3.3.1 below shows the parameters used in each environment:

Table 3.1.1

Environment	λ	β	Δ	α
High	175	1	230	2.05
Medium	150	1	229	1.65
Low	78	.65	120	1.65

. In addition to the conditions established by the parameter values, we also varied other characteristics of the bidding environment that may, according to Charles Rivers and Associates (See CRA Report 1B (1998) pages 5-7), create performance difficulties for the SMR auction. These other characteristics were:

1. Number of bidders
2. Existence of a Competitive Equilibrium (CE)[13]
3. Package Overlap[14]

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[12] See “Testing Combinatorial and Non-Combinatorial Auction Designs: Environment and Testing Protocol Report” prepared for the Federal Communications Commission by Cybernomics Inc., April 12, 1999 (Contract # C-9854019) for a detailed description of the parameter values.

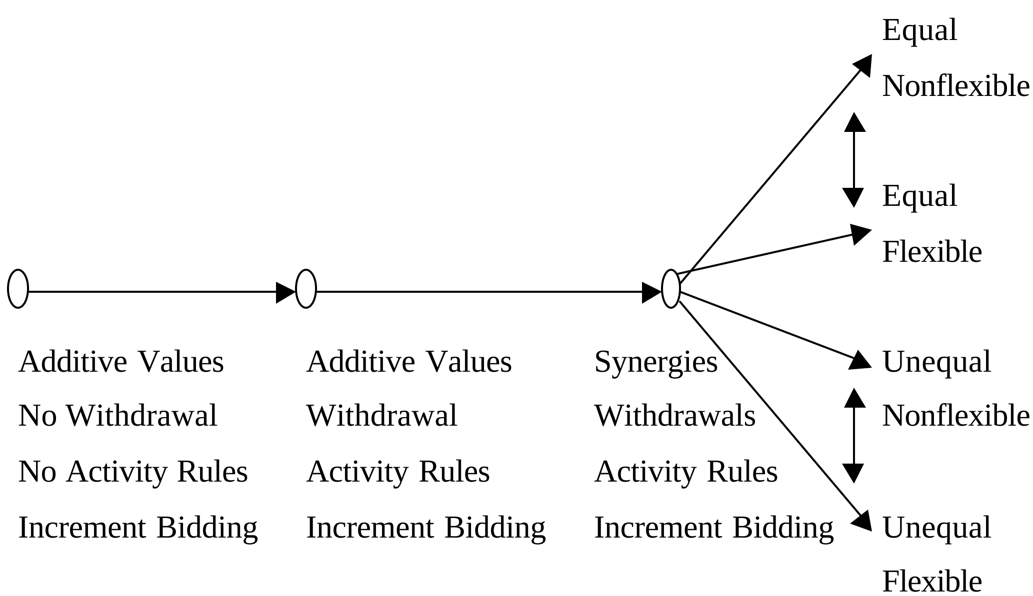
[13] A competitive equilibrium in this environment is a set of license prices such there would be only one demander per license and this allocation would be the efficient allocation.

[14] The algorithm used to select values included a probability function p_{ij} that determined whether license j would be in package i for a bidder. When this probability function is increased, average package size is increased and package overlap across subjects is more likely.

3.4 Subject Pool and Procedures

A total of 150 subjects were recruited from upper-class courses in accounting, information systems, economics and engineering at the University of Arizona. Each subject was trained in the auction rules through a series of 3 two-hour experimental sessions in which each participated in a progression of more complicated SMR rules. Figure 3.4 lists the training progression, and associated treatments, experienced by various subjects. Subjects were considered trained in the treatments listed in Table 3.2.3 after completing the series of training sessions.

Figure 3.4 Subject Training Protocol



As shown above, each subject participated in a series of SMR auctions in which withdrawal rules, activity rules and synergy values were added sequentially to the mechanism and environment. As evidenced in the figure, following the third training step, subjects were divided into two separate groups. One subject group trained exclusively in bidding environments where licenses were assigned unequal eligibility points, while another subject group trained exclusively in bidding environments where licenses were assigned equal eligibility points. Separating subjects in this manner eliminated any possibility that subjects may perform less effectively due to confusion regarding the adopted eligibility rule.

3.5 Bankruptcy

Economic theory suggests that winning bidders may end up losing money in an SMR auction in the presence of superadditivities in valuations. Consequently, we incorporated a *bankruptcy rule* within the SMR auction. Under this rule, which was read aloud to the subjects prior to the experiments, each subject was given $15 at the start of the experiment. If, following the completion of any particular auction within the experiment, a subject's total losses exceeded $15, the subject was considered financially bankrupt and prohibited from continuing to participate in the experiment. The complete rule is provided in Appendix B.

3.6 Design Summary and Procedures

Table 3.6 lists the conducted experiments. An experiment includes a series of SMR auctions. Subjects are assigned different valuation across the auctions. Each auction involved the sale of ten licenses (i.e., A through J). Superadditive valuations applied to two discrete license sets; Set Φ = (A, B, C, D, and E) and Set Ψ = (F, G, H, I and J).[15] Each set was assigned either an additive, or low, medium, or high superadditive value environment. For example, in the first experiment involving the Baseline treatment Set Φ had an additive value environment while Set Ψ had a high superadditive environment. Instructions for each of the treatments can be found at http://linus.econlab.arizona.edu/FCC_Instructions, the experimental parameters used can be found at http://linus.econlab.arizona.edu/FCC_Parameters and the data for each experiment can be found at http://linus.econlab.arizona.edu/FCC_data.

[15] For example, the set of licenses that generate synergy values do not contain elements from sets Φ and Ψ.

Table 3.6 Experimental Design

Treatment	**Experiment**	**Date**	**Environments (Φ,Ψ)**
Baseline	1	4/16/99	Additive, High
Baseline	1	4/16/99	Low, Additive
Baseline	1	4/16/99	High, Medium
Baseline	2	4/21/99	Additive, High
Baseline	2	4/21/99	Low, Additive
Baseline	2	4/21/99	High, Medium
Baseline	3	4/27/99	Low, Additive
Baseline	4	5/3/99	Medium, Low
Baseline	4	5/3/99	Medium, Low
Baseline	4	5/3/99	Low, Additive
Baseline	4	5/3/99	Medium, Low
Baseline	5	5/4/99	Medium, Low
Baseline	5	5/4/99	Low, Additive
Baseline	5	5/4/99	High, Medium
Baseline	6	5/7/99	Additive, High
Baseline	6	5/7/99	High, Medium
Baseline	6	5/7/99	Low, Additive
Baseline	7	8/3/99	Low, Additive
Flexible	1	4/27/99	Medium, Low
Flexible	2	4/29/99	Additive, High
Flexible	2	4/29/99	High, Medium
Flexible	2	4/29/99	Additive, High
Flexible	3	4/30/99	Additive, High
Flexible	3	4/30/99	Low, Additive
Flexible	3	4/30/99	High, Medium
Flexible	4	5/3/99	Additive, High
Flexible	4	5/3/99	Medium, Low
Flexible	4	5/3/99	Medium, Low
Flexible	4	5/3/99	High, Medium
Flexible	5	5/4/99	Additive, High
Flexible	5	5/4/99	Medium, Low
Flexible	5	5/4/99	Medium, Low
Flexible	5	5/4/99	High, Medium
Flexible	6	5/7/99	High, Medium
Flexible	6	5/7/99	Medium, Low
Flexible	7	8/3/99	Low, Additive
Unequal	1	4/16/99	Additive, High

Unequal	1	4/16/99	High, Medium
Unequal	1	4/16/99	Low, Additive
Unequal	2	4/21/99	Additive, High
Unequal	2	4/21/99	High, Medium
Unequal	2	4/21/99	Low, Additive
Unequal	2	4/21/99	Medium, Low
Unequal	3	4/28/99	Medium, Low
Unequal	3	4/28/99	Additive, High
Unequal	3	4/28/99	High, Medium
Unequal	3	4/28/99	Medium, Low
Unequal	4	4/30/99	Medium, Low
Unequal	4	4/30/99	Additive, High
Unequal	4	4/30/99	High, Medium
Unequal	4	4/30/99	Medium, Low
Unequal	4	5/3/99	Low, Additive
Unequal	4	5/3/99	High, Medium
Unequal, Flexible	1	4/20/99	Additive, High
Unequal, Flexible	1	4/20/99	Low, Additive
Unequal, Flexible	1	4/20/99	High, Medium
Unequal, Flexible	2	4/23/99	Additive, High
Unequal, Flexible	2	4/23/99	Low, Additive
Unequal, Flexible	2	4/23/99	Medium, Low
Unequal, Flexible	2	4/23/99	High, Medium
Unequal, Flexible	3	4/26/99	Additive Medium
Unequal, Flexible	3	4/26/99	Additive, High
Unequal, Flexible	3	4/26/99	High, Medium
Unequal, Flexible	4	4/28/99	Medium, Low
Unequal, Flexible	5	4/29/99	Medium, Low
Unequal, Flexible	5	4/29/99	High, Medium
Unequal, Flexible	5	4/29/99	Medium, Low
Unequal, Flexible	6	5/7/99	Additive, High
Unequal, Flexible	6	5/7/99	Low, Additive
Unequal, Flexible	7	8/3/99	Low, Additive

4.0 Experimental Results

A recent Congressional mandate requires that the FCC consider assignment efficiency as the primary measure of performance when evaluating the desirability of using a particular auction mechanism for assigning spectrum licenses. A secondary factor to be considered is the revenue that will be generated by the auction. In addition to these two criteria, we also measured the length of time, expressed in rounds, the auction took to close, and whether winning bidders incurred substantial losses from acquiring their licenses. Auction duration and bidder loss measures have important practical significance. Auctions that take a long time to close impose a heavy transactions cost upon participants, among other things. Similarly, heavy losses by bidders may result in the re-auctioning of the acquired licenses. The re-auctioning of the license extends the period of license non-use and, in so doing, deprives society of important benefits. Finally, we examine the frequency with which participants withdraw high bids. In some environments, a high number of withdrawn bids indicates that bidders are having substantial difficulty in obtaining their most desired licenses.

We use a statistical procedure called "Analysis of Variance" to assess the extent to which the total variation of outcome variables can be explained by changes in the value taken on by one or more of the treatment variables.[16] In general the ANOVA tables will present a column of p-values which indicate the likelihood that any particular variable is influencing the outcome. The lower the p-value the higher the probability that the variable is statistically significant (influential). A p-value below .05 is considered to be a strong indicator of significance. We will use this procedure to study the effect of many different variables on the assignment efficiency, auction revenue, bidder losses, withdrawals, bankruptcies, and auction length. Moreover, this analysis will be conducted on data generated from distinct bidding environments – additive valuations versus superadditive valuations.[17]

4.1 Efficiency

An auction is said to be 100% efficient when it assigns the set of offered items so that the total value that society obtains from the items is maximized. An auction mechanism's ability to efficiently assign items is measured as the ratio of the sum of the values that assignees place on their items divided by the sum of the value maximizing assignment.

[16] See Hoel, P. G. "Introduction to Mathematical Statistics" Chapter 12, Third Edition, John Wiley Press (1962).

4.1.1 Additive Environment

Table 4.1.1a shows the average level of assignment efficiency of the SMR auction under the additive environment for all treatment variable value combinations. Recall that each experiment had two groups of 5 licenses to be allocated in each auction. Each group in the "environment pairing" had a different value structure. We used has the following combined value environments: Additive, Medium:= AM; Low, Additive:= LA; Medium, Low:= ML; and Low, High:= LH. The efficiency below is averaged over all groups of five additive licenses.

Table 4.1.1a Mean (Median) Efficiency by Treatment: Additive Environment

	Nonflexible	**Flexible**
Equal	96.4 (100)	96.9 (100)
Unequal	93.6 (93.8)	96.2 (100)

Table 4.1.1b Count of 100% Efficiency Outcomes by Treatment
Additive Environment (n = number of total experiments)

	Nonflexible	**Flexible**
Equal	6 (n=10)	5 (n=7)
Unequal	3 (n=7)	6 (n=9)

Result 1: Replicating previous studies, the additive environment generates almost perfectly efficient outcomes with no statistically significant difference across the treatments.

[17] The non-existence of a set of competitive equilibrium prices in some superadditive environments makes it impossible to pool the additive and superadditive data, the former of which always has a set of competitive equilibrium prices.

Table 4.1.1a above shows the mean and median efficiency for each treatment. In addition, Table 4.1.1b above shows the count of 100% outcomes in each treatment. In the additive environment 60% of the observations are at the 100% level of efficiency.

Table 4.1.1c below provides the ANOVA table for the analysis of efficiency in the additive environment.

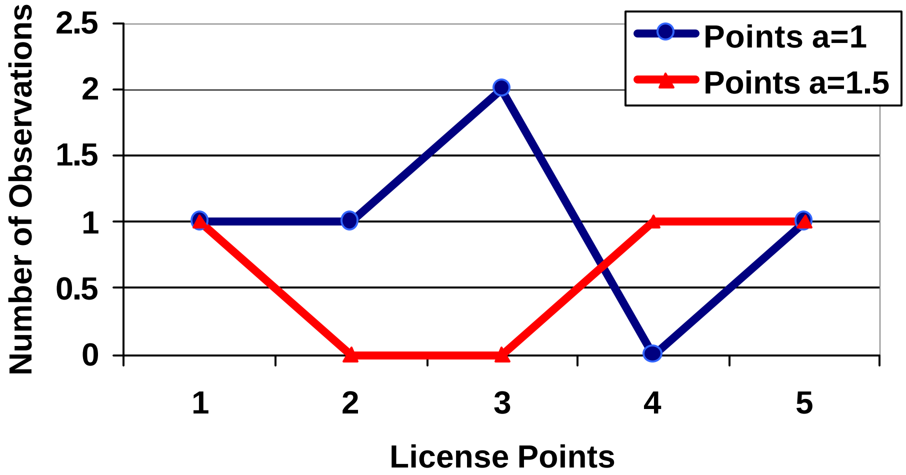
Table 4.1.1c ANOVA Efficiency: Additive Environment

Variable	**F-statistic**	**p-value**
Flexible	0.362	0.552
Unequal	0.700	0.410
Environment Pairing	0.694	0.412
Number of Bidders	1.653	0.211
Flexible$\wedge$Unequal	0.010	0.918

Table 4.1.1c shows that in the additive environment neither treatment (Flexible nor Unequal) has any effect on efficiency, nor does their joint occurrence. (An indicator variable that accounts for the interaction of two variables will be named using the symbol $\wedge$ in this and following tables.) In addition, it shows that there is no significant effect from the number of bidders in the auction or from pairing the additive environment with either a high or medium synergy environment.

The largest number of non-100% outcomes occurs in the treatments in which Unequal eligibility points were used. If subjects were using licenses for option values we would suspect that licenses with the highest eligibility points would be the ones misallocated. This cannot be confirmed by the data (see figure below).

Figure 4.1.1d Inefficiency License Allocation and Points



4.1.2 Superadditive Environment

We conducted experiments with various levels of superadditivity – low (L), medium (M), and high (H) – associated with each subgroup of 5 licenses. Table 4.1.2a provides the (mean, median) for all of the superadditive environments:

Table 4.1.2a Mean (Median) Efficiency by Treatment: Superadditive Environment

	Nonflexible	Flexible
Equal	74.5 (78.5)	82.7 (91.0)
Unequal	65.0 (61.0)	80.4 (91.0)

Table 4.1.2b Count of 100% Efficiency Outcomes by Treatment Superadditive Environment.

	Nonflexible	Flexible
Equal	5 (n=26)	2 (n=29)
Unequal	0 (n=27)	2 (n=25)

In addition to the superadditive value structure of each group of 5 licenses, we assigned three other properties to each group:

1. The **number** of bidders.[18]
2. Whether there exists a **competitive equilibrium** (CE) set of prices for each license at which there would be no excess demand for any license and the efficient allocation is obtained.
3. The degree of **Overlap** among packages. In each environment we selected the average size of the packages that had superadditive values assigned to bidders: the greater the average number of licenses in a package, the greater the overlap.

The effects of the three properties above are included in the ANOVA table that follows:

Table 4.1.2c ANOVA Efficiency: Superadditive Environment

Variable	F-statistic	p-value
Flexible	10.362	0.002
Unequal	2.453	0.121
Environment (H, M, L)	2.467	0.091
Number of Bidders	1.406	0.250
Overlap	3.592	0.005
CE Exists	0.021	0.885
Flexible$\wedge$Unequal	0.578	0.449
Environment$\wedge$Flexible$\wedge$Unequal	0.138	0.871

Result 3: The Flexible treatment has a ***positive*** *and statistically significant effect on assignment efficiency. Overlap has a statistically significant* ***negative*** *effect on efficiency. All other variables are statistically insignificant.*

[18] It was necessary for us to have cases with different numbers of bidders due to the possibility of bankruptcy eliminating some participants.

Thus we find that under superadditive value conditions flexibility provides an important boost to efficiency, while increased density of package overlaps tends to decrease efficiency.

4.2 Revenues

The amount of revenue generated from a particular auction mechanism depends, in part, on the distribution of license valuations across active bidders. This distribution is altered by changes in the number of bidders in the auction: for example, when financial difficulties occur and a bidder decides or is forced to leave. One method of controlling for the confounding effect of changes in the number of bidders on auction revenue is simply to "normalize" auction revenue on the basis of what could be realized given the set of remaining participating bidders and their valuations.

4.2.1 Additive Environment

In the additive environment analysis, we redefine "revenue" as the ratio of revenue actually collected divided by the sum of the competitive prices for the participating agents.

Table 4.2.1a Normalized (Mean, Median) Revenue: Additive Environment

Treatments	**Nonflexible**	**Flexible**
Equal	1.41, 1.31	1.45, 1.45
Unequal	1.39, 1.39	1.31, 1.29

It is easy to see from table 4.2.1a that revenue is significantly above the competitive equilibrium predictions. We will discuss this over-bidding phenomenon in section 4.3 below.

As we did with efficiency we estimate the ANOVA model using the normalized revenues generated from the observed auction outcomes.

Table 4.2.1b ANOVA Normalized Revenue: Additive Environment

Variable	F-statistic	p-value
Flexible	0.218	0.644
Unequal	1.32	0.259
Environment Pairing	0.524	0.598
Number of Bidders	0.005	0.942
Flexible$\wedge$Unequal	1.583	0.219

The ANOVA substantiates the following generic result:

Result 4: There is no statistically significant difference in revenue among the treatments in the additive value environment.

4.3.1 Superadditive Environment

In the superadditive environment analysis, we redefine "revenue" as the ratio of the maximum total value assignment for the participating agents divided by the revenue actually collected. Table 4.3.1a shows these (mean, median) normalized revenue ratios:

Table 4.3.1a Normalized Revenue (Mean, Median): Superadditive Environment

Treatments	**Nonflexible**	**Flexible**
Equal	0.92, 0.89	0.98, 0.91
Unequal	0.72, 0.78	0.84, 0.86

The ANOVA below substantiates the following result:

Result 5: All variables have a significant effect on revenue except for the existence of competitive equilibrium prices.

Table 4.3.1b ANOVA Normalized Revenue: Superadditive Environment

Variable	F-Statistic	P-Value
Flexible	3.267	0.0736
Unequal	10.255	0.0018
Environment (H, M, L)	4.99	0.0086
Number of Bidders	3.368	0.038
Overlap	4.83	0.0005
CE Exists	0.372	0.543

It seems that revenue in the superadditive case is very sensitive. A rule that specifies Unequal points provides lower revenue than one that specifies Equal points. A Flexible eligibility rule provides higher revenues than a Nonflexible rule. The degree of superadditivity of participant packages influences revenue generation (H>M<L). An increase in the number of bidders increases revenue, while more overlap of superadditive packages decreases it.

4.4 Competitive Equilibrium Predictions

A set of competitive equilibrium (CE) prices exists in all the additive value environments and in some of the superadditive value environments. We now check to see if these CE prices are good predictors of the final bids. Because of the use of click-box bidding, the CE prices would be a good predictor of final prices if the latter were within 15% of the former.[19] The Figure 4.4a below shows the box-plot of the relative price outcomes (highest bid / CE price) across each treatment for the additive value environment. In the box plot the dark points shows the medians, the rectangles show the range of the two middle quartiles, and the fences show the range of all other outcomes, with the exception of any outliers which are less than 2/3 or greater than 3/2 of the median. Outliers are shown as hollow points.

In figure 4.4a below which shows price ratios for the additive environment, there are a significant number of instances in which a winning bid exceeds the maximum value of the CE prediction. Ubiquitous jump bidding appears to be the principle culprit, though in a few instances these price discrepancies can be traced to bidders "parking" in licenses (making negative earnings in at least one round on a license).

Figure 4.4a Relative Prices: Additive Values

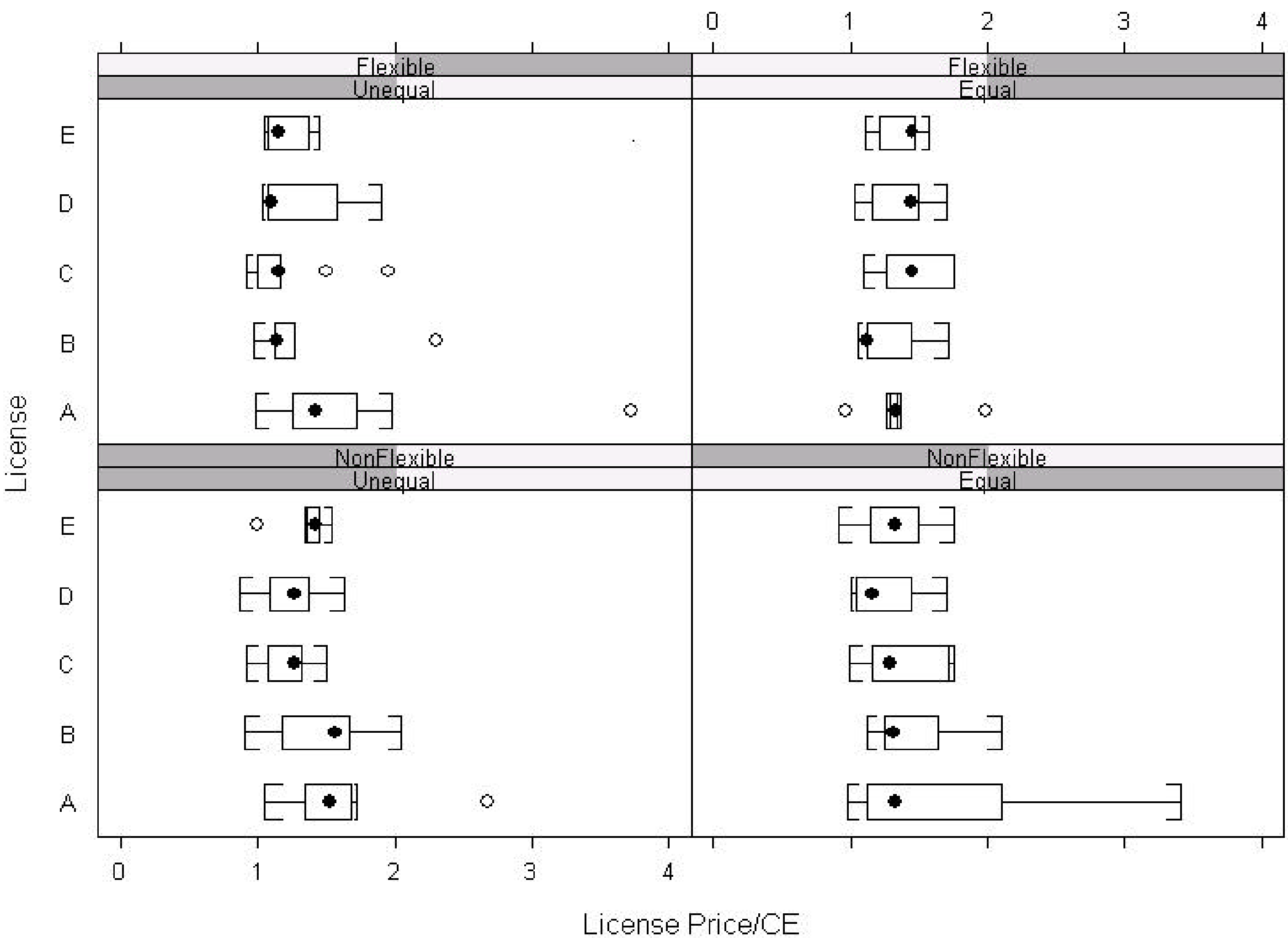
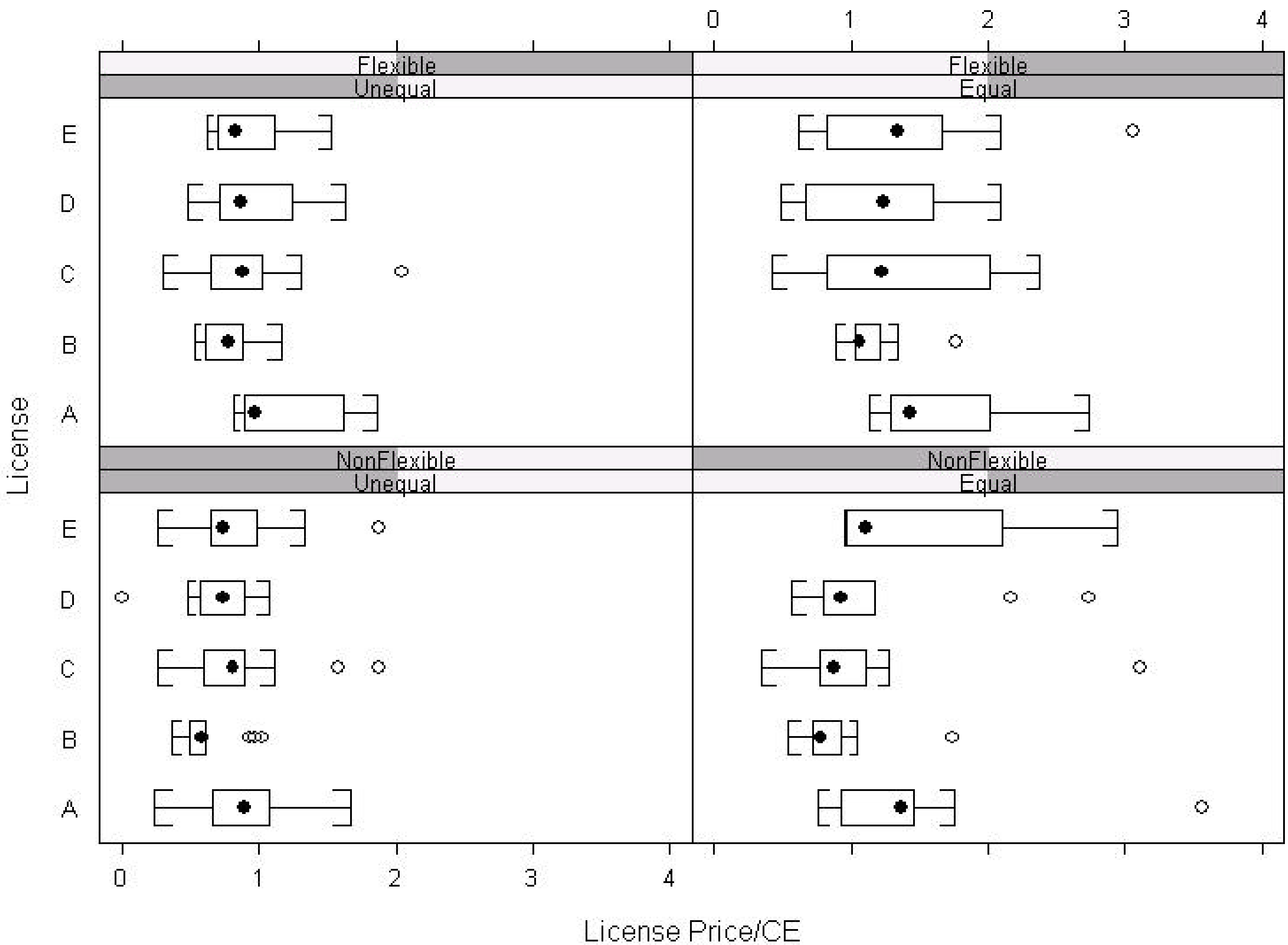


Figure 4.4b below is a box-plot of the relative price outcomes (highest bid / CE price) across treatments for the superadditive value environment when a set of CE prices exists. Figure 4.4b shows winning prices are often lower than the CE range of prices.

[19] Recall that the largest price increment in our SMR experiments was 15% above the standing bid.

Figure 4.4b Relative Prices: Superadditive Values



The above tables strongly suggest the following result:

Result 6: Competitive equilibrium prices are poor predictors of bidding behavior in SMR auctions.

4.5 Bidding Rounds

One proposed factor in evaluating auctions is their duration. A reasonable assumption is that longer auctions should be avoided *ceteris paribus*. This reduces the costs faced by the bidders and the sellers, and thus potentially raises effective valuations and net revenues. Recall that the experimental design we used had the following environment value pairings: Additive, Medium:= AM; Low, Additive:= LA; Medium, Low:= ML; and Low, High:= LH. Within these cases we can determine the treatment effects on rounds. These are presented below in table 4.5.1a:

Table 4.5.1a Average Rounds per Auction and Eligibility Tapering

Treatments	**AM**	**LA**	**ML**	**LH**
Baseline	6.7	7.6	7.3	7.5
Flexible	8.4	8.5	8.4	10.5
Unequal	*6.7*	*7.0*	*7.6*	*7.5*
Unequal Ù Flexible	8.6	9.2	9.1	10.0

It comes as little surprise that, in each environment, a Flexible bidding eligibility rule extends the length of the auction. The ANOVA table below verifies this result:

Result 7: In these experiments the trade-off indicates that when the points scalar is increased from 1.0 to 1.5 the auction lasts approximately 20% more rounds and efficiency increases by 3%.

Table 4.5.1b: ANOVA – Bidding Rounds

Variable	**F-statistic**	**p-value**
Flexible	28.18	0.000
Unequal	3.67	0.058
Environment Pairing	1.26	0.287
CE Exists	1.11	0.294

4.6 Bidder Losses

It may be in the interest of the auctioneer to minimize bidder losses. This need may arise from a desire to accommodate the budget constraints of smaller buyers. An auction that involves the risk of loss may bias auction participation toward larger bidders who can risk small potential losses for the possibility of a large gain. Table 4.6 shows the average losses in cents for each treatment in the additive case. These averages come from exactly two losses in the 165 markets (33 sessions).

Table 4.6.a Per Auction Losses: Additive Environment

Treatments	**Nonflexible**	**Flexible**
Equal	$0.15	$0.00
Unequal	$0.01	$0.00

Result 8: In the additive markets there are virtually no losses.

However things are considerably different when synergies are involved. Table 4.6.b below shows that average losses frequently appear in superadditive environments.

Table 4.6.b Per Auction Losses: Superadditive Environments

Low

Treatments	**Nonflexible**	**Flexible**
Equal	$15.02	$11.31
Unequal	$6.10	$3.64

Medium

Treatments	**Nonflexible**	**Flexible**
Equal	$5.79	$5.09
Unequal	$6.16	$7.04

High

Treatments	**Nonflexible**	**Flexible**
Equal	$12.93	$21.39
Unequal	$8.76	$10.15

In approximately 80% of all auctions across all the treatments there was a loss by at least one bidder. The large average losses in the high synergy case with no points and tapering is skewed by two bankruptcies of $102 and $64.

Table 4.6.c ANOVA Losses per Bidder: Superadditive Environment

Variable	F-statistic	p-value
Flexible	0.047	0.82
Unequal	2.80	0.097
Environment (H, M, L)	1.99	0.141
CE exists	0.60	0.44
Overlap	1.32	0.25
Flexible$\wedge$Unequal	0.11	0.74

The ANOVA results show that at this point we can do no better than speculate that it is the SMR institution itself that is at fault in causing bidder losses, since none of the factors examined appear to be the cause. However, it may be the case that in the bidding environments construed, no auction institution would have performed well in this regard. This remains to be tested.

Result 9: Though losses are a significant and common occurrence in an SMR auction when values have synergies, none of the treatment variables examined provide individually compelling explanations for those losses.

4.7 Bankruptcies

In our experiments bidders participated in a sequence of independent auctions. It was possible for a bidder to incur losses large enough in one auction so that his earnings and working capital were eliminated. In this case the bidder was considered bankrupt, was asked to leave the experiment, and was not able to participate in subsequent auctions during that experimental session. Table 4.7a below shows the average bankruptcies per auction and treatment.

Table 4.7a Per Auction Bankruptcies

All Auctions

Treatments	**Nonflexible**	**Flexible**
Equal	.205	.081
Unequal	.088	.095

Additive

Treatments	**Nonflexible**	**Flexible**
Equal	0	0
Unequal	0	0

Low

Treatments	**Nonflexible**	**Flexible**
Equal	.25	.143
Unequal	0.125	0

Medium

Treatments	**Nonflexible**	**Flexible**
Equal	0.125	0
Unequal	0.1	0.125

High

Treatments	**Nonflexible**	**Flexible**
Equal	.444	.182
Unequal	.111	.25

The ANOVA table below provides no statistically significant relationships, but we may simply observe from the tables above that:

Result 10: Bankruptcy never occurred in the additive environment and had the highest aggregate frequency in the high synergy environment.

Table 4.7b: ANOVA-Bankruptcies per Bidder: Superadditive Environment

Variable	F-statistic	p-value
Flexible	1.1547	0.28
Unequal	1.25	0.26
Environment (H,M,L)	1.43	0.24
CE exists	0.05	0.813
Overlap	1.17	0.32

4.8 Withdrawals and Combined Withdrawal and Bidding

One bidding option available to bidders in the SMR auctions is the ability to withdraw a standing bid. This withdrawal does not come without a cost. The tables below show the average number of withdrawals per auction. Across all treatments and environments the average number of withdrawals was less than 1.

Table 4.8a: Average Withdrawals Per Auction

Treatments	**Nonflexible**	**Flexible**
Equal	.723	.525
Unequal	.410	.519

Additive

Treatments	**Nonflexible**	**Flexible**
Equal	.05	.03
Unequal	0	0

Low

Treatments	**Nonflexible**	**Flexible**
Equal	.98	.571
Unequal	.75	.444

Medium

Treatments	**Nonflexible**	**Flexible**
Equal	.98	.454
Unequal	.2	.875

High

Treatments	**Nonflexible**	**Flexible**
Equal	.444	.818
Unequal	.667	.75

Though the average number of withdrawals was few, withdrawals predictably occurred when synergies were high.

Table 4.8b ANOVA - Withdrawals per Bidder: Superadditive Environment

Variable	**F-statistic**	**p-value**
Flexible	0.002	0.95
Unequal	0.59	0.44
Environment	0.08	0.92
CE exists	0.12	0.719
Overlap	2.34	0.047

The ANOVA table suggests that, of the treatments considered, only Overlap conditions increased the probability of a withdrawal.

To speed-up the SMR auction CRA Report 1A (1998) pgs 3-4 and 8-9 recommended combining the withdrawal and bidding portion of the auction in each round. The implementation of this rule, as defined by the FCC, requires that the bidder who is withdrawing a bid cannot also submit a bid on that license in the round in which he is withdrawing it. During our experiments we observed many cases in which withdrawals occurred late in the auction as participants were shedding eligibility. In over 50% of the cases in which a withdrawal occurred, the individual withdrawing did not know that others were simultaneously reducing their eligibility. The end effect was that these individuals gave up licenses that no one else picked up: the license reverted to the auctioneer and the withdrawing individual paid a full withdrawal penalty.

The table below shows, for the synergy value environments, the number of licenses that went unsold at the end of the auction due to withdrawal versus the number of total withdrawals. Every withdrawal tendered in the auction occurred when the bidder was losing money from a failed aggregation. We could not detect any use of withdrawals for strategic reasons like those suggested in the CRA report.

Table 4.8c Unsold Withdrawals Per Auction

Treatments	**Nonflexible**	**Flexible**
Equal	9 out of 25	12 out of 22
Unequal	6 out of 14	9 out of 21

We conclude with the following final result that throws caution to the notion that simultaneous withdrawals and bidding are a good idea.

Result 11: Environments with high synergy will always produce withdrawals in an SMR auction.. Many of those withdrawals will occur toward the end of the auction, and approximately 33% will remain unsold often because a potential buyer gives up eligibility in the same round not being informed that the license will become available in the next round at a much lower price.

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