

## **Appendix A: Rules for the SMR Laboratory Auctions**

Rounds and Bid Structure: All licenses are put up for bid simultaneously, and participants may only submit bids on individual licenses. The auction consists of successive rounds in which participants may place bids. Following each round, the high bid for each license is posted. These high bids then become the standing bids for the subsequent round.

Acceptable Bids: In the first round, an acceptable bid must be equal to or exceed the initial price of 0 by 5 points (each point equaled 40 cents in the experiment). Subsequently, in order to be acceptable, a bid must exceed the provisionally winning bid for the license by at least 5 points. Bidders are given the choice of making one of eight incrementally higher bids (in 5 point increments).

Bid Withdrawal: Each bidder has at most 2 rounds in which they are permitted to withdraw any of their provisionally winning bids. After the withdrawal, the seller becomes the provisionally winning bidder for the withdrawn license and the minimum acceptable bid in the following round equals the second highest bid received on the license, which may be less than or equal to (in the case of tied bids) the amount of the withdrawn bid. A withdrawing bidder pays a penalty equal to the maximum of zero or the difference between the price at which the bidder withdrew its bid and the final sale price in the current auction. If the license goes unsold, the bidder would normally be responsible for paying the difference between the withdrawn bid and the sale price in a subsequent auction, plus a small percentage penalty of 3 percent. In the experiment, there is no subsequent auction, so these penalties for the case of an unsold license were implemented by requiring that the bidder pay a penalty of 25 percent of the withdrawn bid.

Bidding Eligibility and Activity: Each license in the experiment is assigned one bidding unit. The total number of bidding units available to the bidder establishes the bidder's maximum "eligibility" to bid. National bidders begin each auction with 6 activity units and regional bidders begin with 3. In each round, a bidder's activity is calculated as the number of licenses for which that bidder is a provisional winner, plus the number of licenses for which acceptable bids are submitted. If a bidder's activity falls below the bidder's current activity limit, that limit is reduced to equal the bidder's actual activity. There were no activity rule waivers in the experiment, so a reduction in activity would put an upper limit on the bidder's activity for all subsequent rounds of that auction.

End of Round Feedback: At the end of each round, bidders receive information on all provisionally winning bids, withdrawn bids, and the corresponding bidder ID numbers. Bidders also see the sum of their own values for the licenses that they are provisionally winning and prices that would be paid for the licenses if the auction had ended.

Closing Rule: The auction closes after any round in which no new bids were placed and no bids were withdrawn. In this case provisionally winning bids become winning bids that are used to calculate auction earnings. The experiment did not allow for defaults on payments, so gains were added to cumulative earnings and losses were subtracted.

## **Appendix B: Rules for RAD (in Bold) and SMRPB (in Italics)**

Rounds and Bid Structure: This is a simultaneous, multi-round auction in which participants may submit one or more bids on individual licenses or on combinations of licenses (packages). Provisionally winning bids are calculated by maximizing seller revenue for the round, using all current and past bids. (*SMRPB: Bids have an exclusive “XOR” structure in the sense that each bidder can have at most one provisionally winning bid.*)

Acceptable Bids: In the first round, an acceptable bid must be equal to or exceed the minimum opening bid of 0 by 5 points for each license, or by 5 points times the number of licenses in a package. After each subsequent round, “prices” are calculated for each license on the basis of bids received in the previous round. The pricing rule, as specified in Appendix D of the Experiment Design Report, calculates prices that reflect (as closely as possible) the marginal sales revenue of each license based on bids received. Prices for packages are the given by the sum of the prices for each license in the package. In order to be acceptable, a bid must exceed the price of a license or package at least 5 points times the number of licenses covered by the bid. Bidders are given the choice of making one of eight incrementally higher bids (in 5 point increments).

Bidding Eligibility and Activity: Each license in the experiment is assigned one bidding unit. The total number of bidding units available to the bidder establishes the bidder’s maximum “eligibility” to bid (3 for regional bidders and 6 for national bidders). (**RAD: In each round, a bidder’s activity is calculated as the number of different licenses for which that bidder is a provisional winner or for which that bidder places a bid, either singly or as part of a package.**) (*SMRPB: In each round, a bidder’s activity is calculated as the maximum of (1) the size of the largest package the bidder is provisionally winning and (2) the size of the largest package the bidder is bidding for.*) If a bidder’s activity falls below the bidder’s current activity limit, that limit is reduced to equal the bidder’s actual activity. There were no activity rule waivers in the experiment, so a reduction in activity would put an upper limit on the bidder’s activity for all subsequent rounds of that auction.

End of Round Feedback: At the end of each round, bidders receive information on all provisionally winning bids (for licenses and packages) and the corresponding bidder ID numbers. Bidders also see the prices for all licenses, the sum of their own values for the licenses and packages that they are provisionally winning, and the sum of prices that would be paid for those licenses and packages if the auction had ended.

Closing Rule: The auction closes after any round in which no new bids were placed. In this case provisionally winning bids become winning bids that are used to calculate auction earnings. The experiment did not allow for defaults on payments, so gains were added to cumulative earnings and losses were subtracted.

## **Appendix C: Rules for the Combinatorial Clock (CC)**

Rounds and Bid Structure: This is a simultaneous, multi-round auction in which participants may submit one or more bids on individual licenses or on combinations of licenses (packages). Submitted bids stay active until they are removed (just as provisionally winning bids in the other formats are automatically renewed).

Acceptable Bids: In the first round, an acceptable bid must be equal to or exceed the minimum opening bid of 0 by 5 points for each license, or by 5 points times the number of licenses in a package. After each subsequent round, “prices” are calculated for each license on the basis of bids received in the previous round. If a license is in the contained in a bid made by more than one bidder (individually or as part of a package), then the price for that license will rise by the bid increment (5), otherwise the price does not change. For example, if one bidder is bidding on A and AB, and if the only other bidder is bidding on B, then the price of B will increase and the price of A will stay unchanged. Prices for packages are the given by the sum of the prices for each license in the package, so the price of a package can increase by at most the product of the bid increment and the number of licenses in the package.

Bidding Eligibility and Activity: Each license in the experiment is assigned one bidding unit. The total number of bidding units available to the bidder establishes the bidder’s maximum “eligibility” to bid (3 for regional bidders and 6 for national bidders). In each round, a bidder’s activity is calculated as the number of different licenses for which that bidder places a bid, either singly or as part of a package. For example, a regional bidder with an initial activity limit of 3 would be able to bid on packages BC and on ABC, but not on ABC and E. If a bidder’s activity falls below the bidder’s current activity limit, that limit is reduced to equal the bidder’s actual activity. There were no activity rule waivers in the experiment, so a reduction in activity would put an upper limit on the bidder’s activity for all subsequent rounds of that auction.

End of Round Feedback: At the end of each round, bidders receive information on all prices and submitted bids (for licenses and packages), with the corresponding bidder ID numbers.

Closing Rule: The auction generally closes after any round in which there is no excess demand, i.e. no license is in the “bidding basket” of more than one person. However, if there is excess supply at this point (one or more unclaimed licenses), then a revenue maximization routine is run using all submitted bids in all rounds in order to arrange the sale of all licenses. If the resulting allocation displaces the sole remaining bidder for any of the licenses, the auction is restarted and the clock prices on those licenses are raised to let those bidders have the chance to reclaim them.

## Appendix D: Efficiency, Revenue, and Profits by Auction Format

	HOHC				LOHC				HOLC				LOLC			
	SMR	CC	RAD	SMRPB	SMR	CC	RAD	SMRPB	SMR	CC	RAD	SMRPB	SMR	CC	RAD	SMRPB
<b>Efficiency</b>																
Wave 1	86%	92%	89%	88%	86%	89%	93%	89%	96%	92%	95%	88%	96%	82%	94%	93%
Wave 2	85%	94%	89%	93%	79%	91%	89%	91%	96%	93%	95%	84%	97%	93%	93%	86%
Wave 3	84%	86%	94%	93%	85%	87%	94%	87%	98%	96%	98%	93%	96%	96%	99%	92%
<b>Average</b>	<b>85%</b>	<b>91%</b>	<b>90%</b>	<b>91%</b>	<b>83%</b>	<b>89%</b>	<b>92%</b>	<b>89%</b>	<b>97%</b>	<b>94%</b>	<b>96%</b>	<b>88%</b>	<b>96%</b>	<b>90%</b>	<b>95%</b>	<b>90%</b>
<b>Revenue</b>																
Wave 1	54%	70%	56%	46%	40%	59%	50%	49%	30%	46%	40%	21%	30%	47%	29%	38%
Wave 2	55%	71%	52%	44%	42%	56%	38%	48%	32%	42%	33%	15%	28%	40%	41%	36%
Wave 3	42%	51%	43%	41%	38%	45%	42%	33%	30%	35%	23%	28%	24%	39%	34%	23%
<b>Average</b>	<b>50%</b>	<b>64%</b>	<b>50%</b>	<b>44%</b>	<b>40%</b>	<b>53%</b>	<b>43%</b>	<b>43%</b>	<b>31%</b>	<b>41%</b>	<b>32%</b>	<b>21%</b>	<b>27%</b>	<b>42%</b>	<b>35%</b>	<b>32%</b>
<b>Profit Nationals</b>																
Wave 1	3%	3%	10%	10%	4%	1%	1%	-3%	4%	2%	-3%	5%	3%	2%	0%	2%
Wave 2	-4%	3%	6%	7%	-2%	3%	4%	2%	4%	2%	3%	1%	2%	1%	4%	4%
Wave 3	1%	5%	9%	6%	1%	2%	1%	2%	3%	0%	3%	4%	1%	1%	4%	2%
<b>Average</b>	<b>0%</b>	<b>4%</b>	<b>8%</b>	<b>8%</b>	<b>1%</b>	<b>2%</b>	<b>2%</b>	<b>0%</b>	<b>3%</b>	<b>2%</b>	<b>1%</b>	<b>3%</b>	<b>2%</b>	<b>1%</b>	<b>3%</b>	<b>3%</b>
Losses	2%	0%	0%	0%	0%	0%	0%	2%	0%	0%	1%	0%	0%	0%	0%	0%
<b>Profit Regionals</b>																
Wave 1	29%	19%	23%	32%	48%	29%	41%	43%	62%	44%	58%	63%	63%	32%	64%	53%
Wave 2	33%	19%	31%	42%	38%	32%	47%	42%	60%	49%	59%	68%	66%	52%	48%	46%
Wave 3	41%	31%	41%	46%	46%	40%	51%	52%	65%	60%	72%	60%	71%	56%	61%	67%
<b>Average</b>	<b>34%</b>	<b>23%</b>	<b>32%</b>	<b>40%</b>	<b>44%</b>	<b>33%</b>	<b>47%</b>	<b>46%</b>	<b>63%</b>	<b>51%</b>	<b>63%</b>	<b>64%</b>	<b>67%</b>	<b>47%</b>	<b>58%</b>	<b>55%</b>
Losses	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	1%	1%	1%
<b># Rounds</b>	<b>15.2</b>	<b>22.8</b>	<b>24.2</b>	<b>17.1</b>	<b>16.3</b>	<b>22.8</b>	<b>22.2</b>	<b>18.7</b>	<b>13.7</b>	<b>18.1</b>	<b>16.4</b>	<b>17.9</b>	<b>14.9</b>	<b>18.8</b>	<b>15.8</b>	<b>21.8</b>
<b>Unsold Licenses</b>	<b>4%</b>	<b>1%</b>	<b>0%</b>	<b>0%</b>	<b>7%</b>	<b>0%</b>	<b>0%</b>	<b>0%</b>	<b>0%</b>	<b>1%</b>	<b>0%</b>	<b>0%</b>	<b>0%</b>	<b>0%</b>	<b>0%</b>	<b>0%</b>