Online Appendix to "Theoretical and Experimental Analysis of Auctions with Negative Externalities": Experimental Results for the Entire Session

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In the analysis that follows, data will be reported for the entire set of auctions. Results are similar to those for the last 12 auctions in each experimental session. In what follows we the report the experimental results by the same order in the full paper.

1 Bidding in Clock Auctions

1.1 First Drop Outs

Figures 1 and 2 shows the first drop price against values in the clock auctions for Rs and Es separately, along with the equilibrium bid functions.[1] There is a mass of zero, or close to zero, bids on the part of Rs with values in the interval [0, 50] as the theory predicts: R's with values less than or equal to 50 dropped at or before the clock auction started 28.8% of the time.[2] There are also a number of drops at, or close to value (the 45 degree line), representing a failure to free ride, even at low values. Further, Rs' stage-one drops along the 45 degree line, although not the free riding the theory predicts, stand in market contrast to the frequency with which Rs drop with bids *above* their value

[1] This figure excludes the 19 cases in which a bidder who dropped prior to the start of the auction and lost the SPSB auction.

[2] In contrast, when an R's value was greater than 50, he/she dropped out before the clock started less than 1% of the time. For Es with values less than or equal to 50, the overall frequency of dropping before the clock started was 12.0%. Both of these actions represent out-of-equilibrium play.

(or win the auction with bids *above* value) when competing with Es after stage-one (see Figure 3 and 4 below).

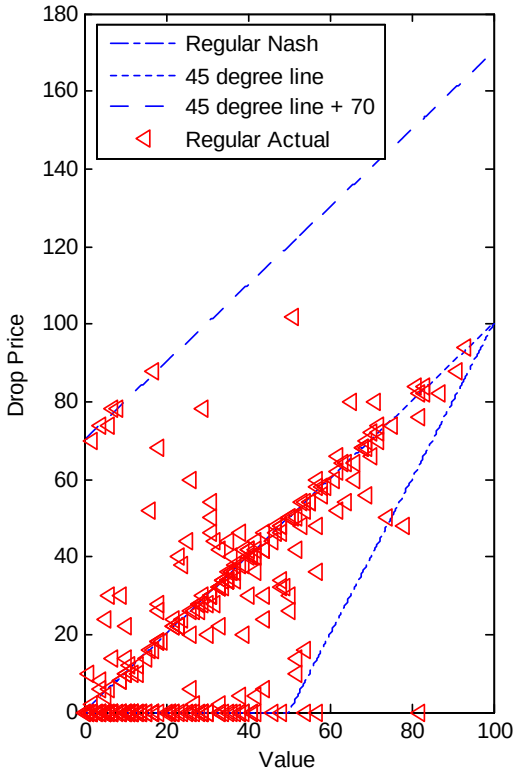

Figure 1: First Drop Prices for Rs

1.2 Stage-Two Bids

Figures 3 and 4 show, respectively, drop outs and winning bids for those sub-auctions where the remaining bidders were an E and an R. Two factors stand out. First, there are a large number of instances in which Es, contrary to the dominant bidding strategy, dropped out with bids above their values (57.9% of all Es dropping out second), but only a handful of auctions where Es wound up with a winning bid above their value (4.7% of these sub-auctions).[3] Second, there were large numbers of

[3] Amending these calculations to allow for rounding error, or momentarily being distracted as the clock ticked up, to bidding above value + 4 ECUs, these percentages become 47.5% and 3.6%, respectively. Es won 39 auctions in

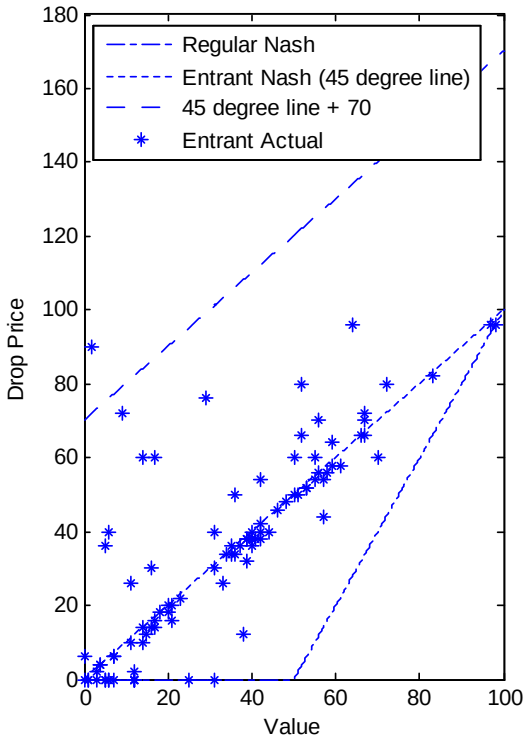

Figure 2: First Drop Prices for Es

auctions in which Rs won with bids above their value (but less than the externality; 50.9% of these sub-auctions). There was some heterogeneity in the extent to which Es consistently bid in excess of their value, with 40.0% of Es bidding above their value more than 50% of the time.[4] In contrast, 100% of Rs either won or bid up to their value plus the externality more than 50% of the time.

Figure 5 reports dropouts and winning bids for those sub-auctions where both bidders were Rs. In this case Rs' behavior is generally consistent with the dominant strategy as drop out prices hover around the 45 degree line, and there were only five auctions in which Rs won with bids above their value when competing against another R.[5]

total, with losses in 13 of the auctions. In 10 of these 13 auctions, Rs dropped out prior to bidding up to their value plus the externality. In equilibrium, Es would have won 3 of these 39 auctions.

[4] This includes winning bids above value.

[5] Dropped from Figure 5 are those sub-auctions in which when E dropped both Rs were still active with one or both bidding above their value. There is an obvious incentive in these cases for Rs bidding above value to drop immediately,

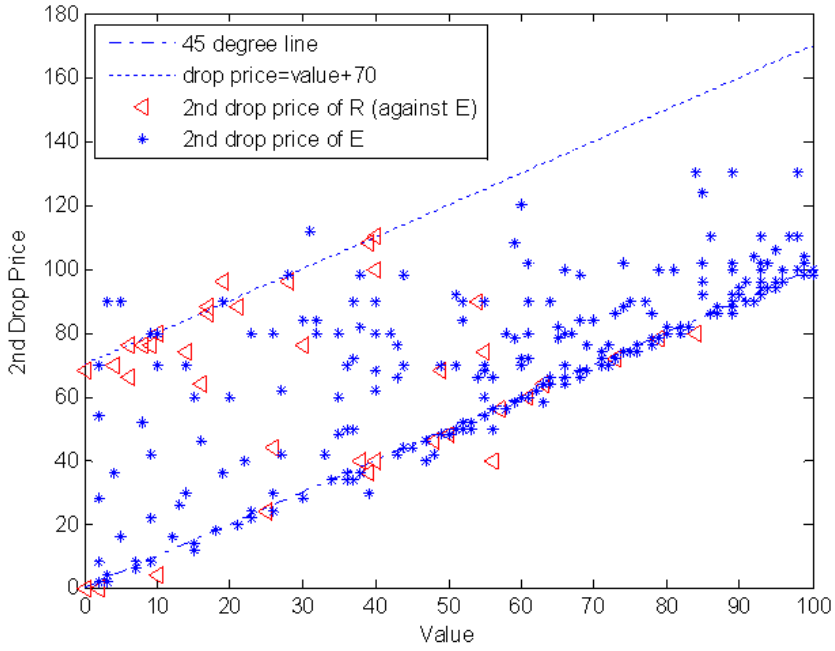

Figure 3: Stage-Two Bids in Clock Auctions: Both R and E Active

As for the discussion on the high frequency of Es bidding above their value, consistent with the results for the last 12 auctions, Figure 3 again shows that Es bidding above value tapers off a bit for values above 70.[6] And there are still relatively few bids below value in Figure 3.

2 Bidding in FPSB Auctions

Figure 6 plots bids for Rs and Es in the FPSB auctions, along with the equilibrium bid functions. The graph shows that Rs bid higher than Es, on average, for all valuations, with Rs' bids at lower valuations closer to their value plus the externality than the risk-neutral Nash equilibrium (RNNE). Figure 7 graphs bids for Rs compared to the controls, with Rs bidding higher than the controls, on average, at all valuations. Note that 7 shows the standard result for independent private value

which most of them did.

[6] When Es dropped second in these sub-auctions, their frequency of dropping above value plus 4 ECUs was 55.2% for values less than or equal to 70 and 33.7% for values above 70.

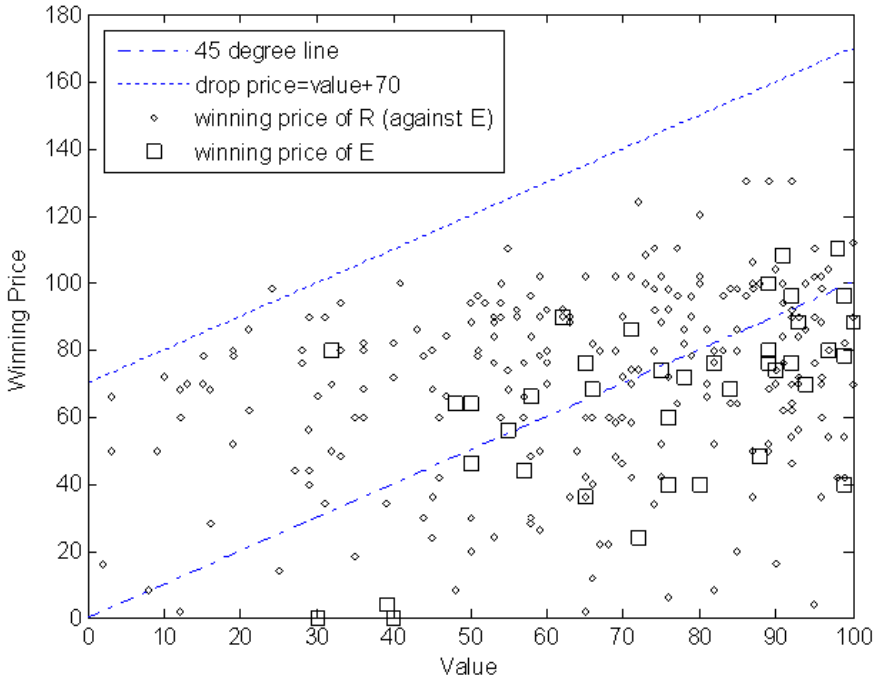

Figure 4: Wining Prices in Clock Auctions: Both R and E Active in Stage 2

FPSB auctions – massive bidding above the RNNE, with Rs bidding even higher than that. Figure 8 shows bids of Es compared to the controls. Es tend to bid higher than the controls, particularly at higher valuations. This occurs in spite of the rather massive overbidding relative to the RNNE in the controls. Finally, there is minimal bidding above value for Es and the controls, with no bids above their value plus the externality for Rs.[7]

Random effect regressions, with subject as the random component, reported in Table 1 confirm these results. In these regressions we have dropped bids for valuations less than 10 as (i) the equilibrium bid function with externalities has its most pronounced non-linear component in the interval [0, 10], and (ii) at low valuations there is some tendency for "throw away" bids as subjects realize they have very little chance of winning the auction with very low valuations.Several specifications are reported, with and without a v^2 term. All of the specifications treat the controls as the reference point against which to compare Rs and Es bids. There is a separate dummy variable with value 1 if

[7]For Es 2.13% of bids were above value. For the controls, 0.93% of all bids were above value.

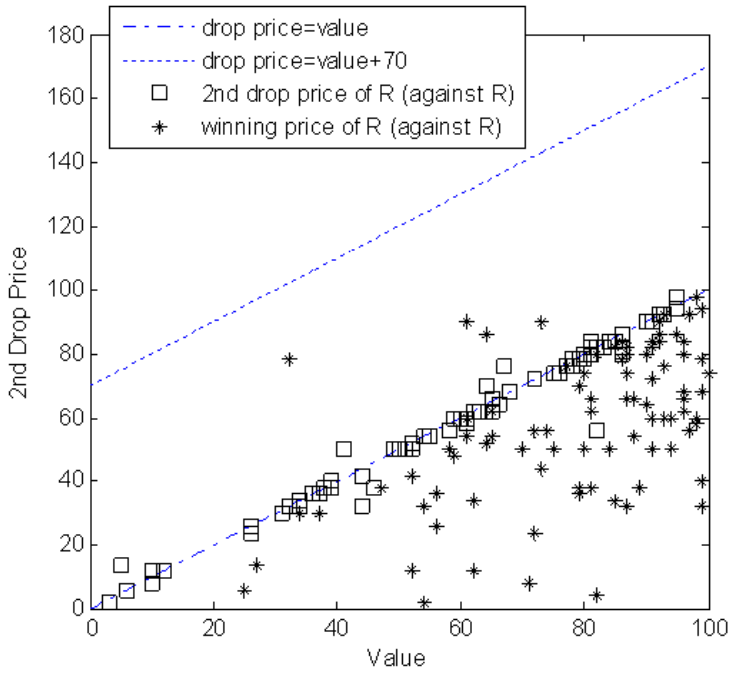

Figure 5: Stage-Two Bids and Winning Prices in Clock Auctions: Both Rs Active

the subject is an R, and 0 otherwise, a separate dummy with value 1 if the subject is an E, and 0 otherwise, and interaction terms for each of the two dummies and v, and for the two dummies and the v^2 term. *The R^*v^2 interaction is positive and significant at the 5% level.* Although including the E*v^2 shows that it is not statistically significant in its own right, and results in the E*v interaction term no longer being statistically significant, a chi-square test shows that we can reject a null hypothesis at the 1% level that the E*v interaction terms and the E*v^2 interaction terms are jointly equal to zero.

Figure 9 plots the estimated bid functions for Rs, Es and the controls for the right hand most specification in Table 1, our preferred specification. Evaluating the estimated bid function for this specification, Rs were bidding significantly more than the controls ($p < 0.05$) for all valuations as the theory predicts. Similarly, Es were bidding significantly more than the controls ($p < 0.05$) for higher valuations ($v > 45$), with the differences between Es and the controls not significantly different from each other for values less than this. Finally Rs were bidding significantly more than Es at lower valuations ($v < 79$), with no significant differences between the two at higher valuations. These

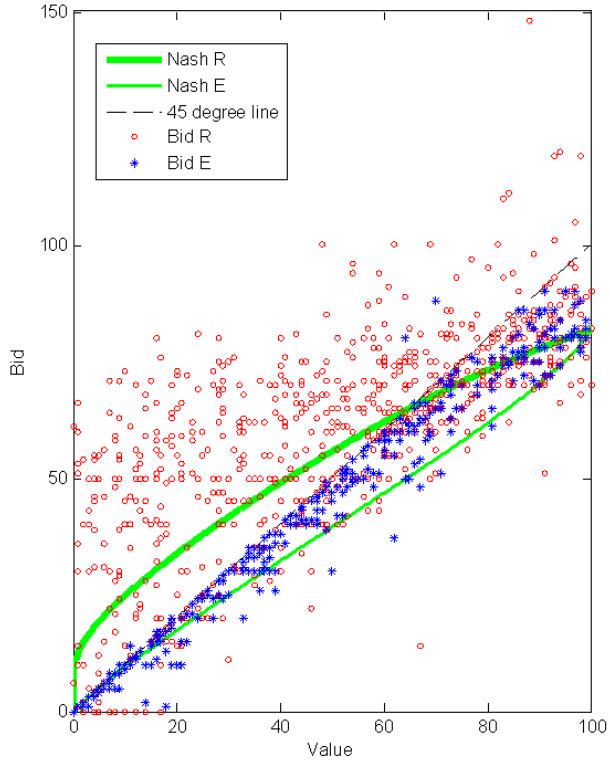

Figure 6: Bids in FPSB Auctions with Externality Present

results are all qualitatively consistent with the theory since differences in bids between Es and Cs are minimal at lower valuations, with differences in bids between Rs and Es growing smaller at higher valuations. As a side note, the negative sign for the v^2 term reflects the fact that at the very highest valuations the tendency to bid well above the risk-neutral NE in IPV FPSB auctions tends to be moderated (see, for example, Dorsey and Razollini, 2003).

Table 1: Random Effect Regressions. Dependent Variable: Bids in FPSB Auction

	FPSB w/ & w/o Externality		
		Value>10	
Period	1-25	1-25	1-25
Constant	2.36***	-1.94	-2.96***
	(0.56)	(1.15)	(1.04)
E Dummy	-1.24	-1.33	-1.36
	(1.04)	(1.00)	(1.60)
R Dummy	31.10***	31.14***	36.10***
	(3.43)	(3.43)	(4.46)
Value	0.80***	0.96***	1.05***
	(0.02)	(0.05)	(0.05)
E×Value	0.08***	0.08***	0.08
	(0.02)	(0.02)	(0.07)
R×Value	-0.27***	-0.27***	-0.51***
	(0.05)	(0.05)	(0.13)
$Value^2$	-	-0.0014***	-0.0023***
		(0.0005)	(0.0005)
E×$Value^2$	-	-	0.000008
			(0.000655)
R×$Value^2$	-	-	0.0021**
			(0.0008)
Obs	1678	1678	1678
R-sqrd	0.80	0.80	0.80

Standard deviations in parenthesis. ***Significant at 1 percent level, two tailed test; **Significant at 5 percent level, two tailed test; * Significant at 10 percent level, two tailed test.

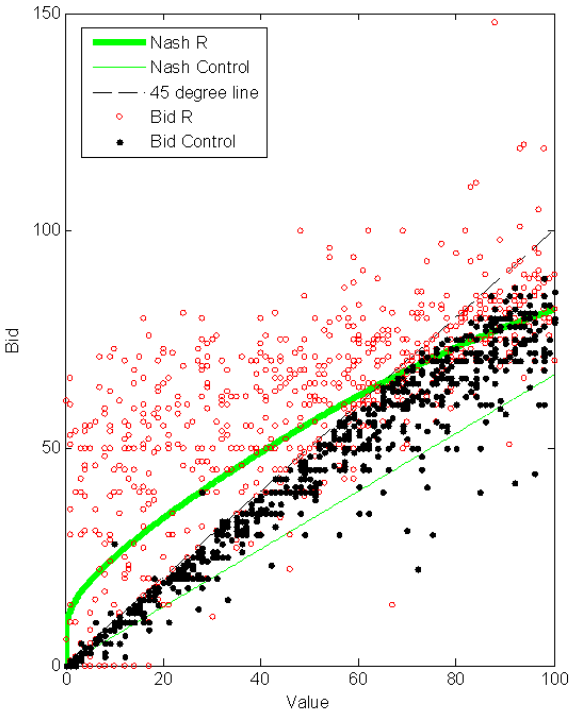

Figure 7: Bids in FPSB Auctions: Rs versus Controls

3 Revenue and Efficiency[8]

3.1 Revenue

Table 2 compares average revenue under the two auction formats where predicted revenue is based on auction valuations used in the experiment. Predicted revenue is higher under the FPSB auction than

[8]Statistical tests throughout this section are based on OLS regressions in which the dependent variable consists of session average values for the variable in question and right hand side variables consist of dummy variables for the treatment conditions. For example, with revenue as the dependent variable, right hand side variables consist of a dummy variable for FPSB auctions with the negative externality = 1 (0 otherwise) and a dummy for the FPSB control auctions = 1 (0 otherwise), with the omitted treatment (English clock auctions) represented by the constant. Use of session value averages for the dependent variable represents the very conservative assumption that each auction session is a single observation because of complete autocorrelation of observations due to random re-mixing of subjects between auctions (see Frechette, 2012, for a discussion of statistical issues involved in, and alternative ways of dealing with, the typical practice of re-mixing subjects between rounds in experiments). Given the clear theoretical predictions regarding efficiency and entry rates between the clock and FPSB auctions, one-tailed statistical tests are justified and used in Table 2.

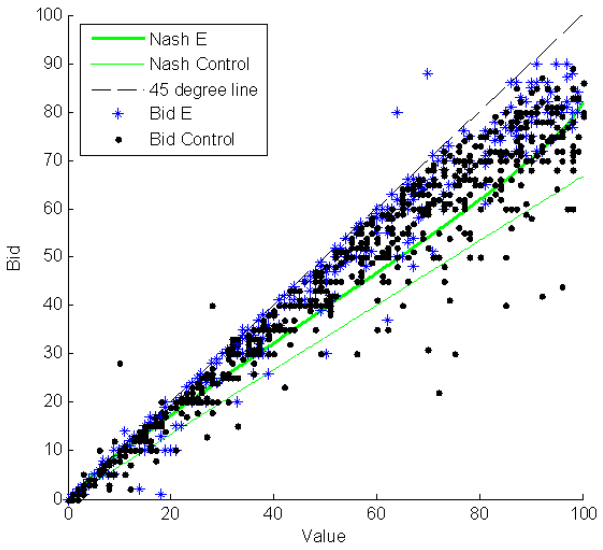

Figure 8: Bids in FPSB Auctions: Es versus Controls

under the clock auction. Actual revenue is substantially higher than predicted revenue in the FPSB auctions, which is not unexpected given the overbidding (relative to the RNNE) typically found in FPSB auctions without externalities. Actual revenue is substantially higher than predicted revenue in the clock auctions as well. This is a result of Es bidding above value. *Revenue is significantly higher in the FPSB auctions than in the clock auctions ($p<0.01$).*

Absent a negative externality, and assuming risk neutral bidders, the variance in revenue in English auctions is predicted to be greater than in the FPSB auctions. With the negative externality this tendency is exaggerated as the remaining incumbent bidder is willing to bid up to his value to forestall entry, with the entrant bidding up to his value. This prediction is indeed satisfied in our experiment with the variance in revenue in the English auctions substantially higher than in the FPSB auctions (694.8 versus 187.9; $p < 0.01$).

Finally, as expected, average revenue is significantly higher in the FPSB auctions with the negative externality than in the FPSB no externality auctions ($p < 0.01$). Average revenue is higher in the clock auctions with the negative externality than in the FPSB no externality auctions, *but this difference is not statistically significant at convertional levels.*

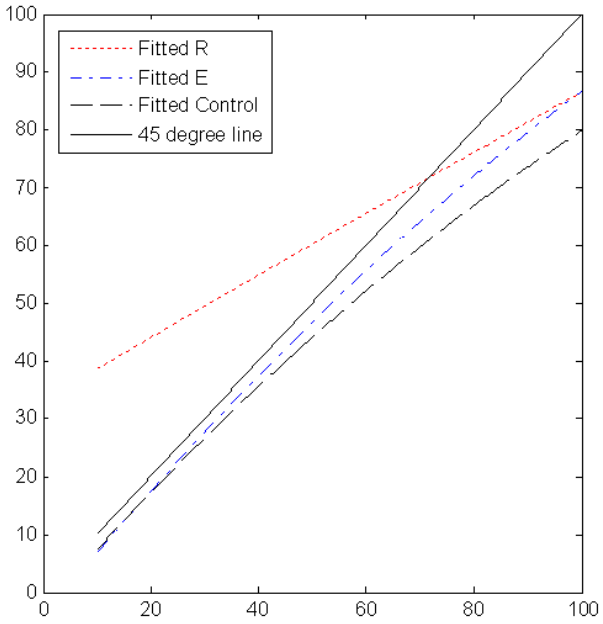

Figure 9: Estimated Bid Functions for FPSB Auctions: v>10, including Vsq.

3.2 Efficiency

We measure efficiency strictly in terms of the frequency with which the highest valued bidder wins the auction. In calculating this, Rs value include the cost of the externality as well as their private value. In equilibrium the clock auction is predicted to be 100% efficient because free riding only exists in the first-stage of the auction, with bidders having a dominant strategy to bid up to their valuations after that. In contrast, the FPSB auction with the externality is akin to an auction with asymmetric valuations, so that efficiency will, in general, be less than 100%.

Table 2 reports average predicted and actual efficiency in the two auction formats with the externality present, where predicted efficiency is for the auction valuations actually drawn. Actual efficiency is significantly lower in the FPSB auctions than in the clock auctions, with the difference reasonably close to the predicted difference, in spite of the fact that absolute efficiency values are well below predicted levels in both cases. Note that the efficiency measure here excludes any potential increase in efficiency for the market in question given the predicted increase in entry fro the FPSB

Table 2: Revenue, Efficiency and Percent of Auctions E Win

	Ascending clock		**FPSB**		**Difference**	
	Actual	Predicted	Actual	Predicted	Actual	Predicted
Revenue	67.61	61.59	74.67	67.08	7.06***	5.49
	(1.36)	(1.45)	(0.71)	(0.64)		
Efficiency	78.13	100.00	63.73	82.40	-14.40***	-17.60
	(2.14)	(0.00)	(2.49)	(1.97		
% E Win	10.40	0.80	21.07	19.73	10.67**	18.93
	(1.58)	(0.46)	(2.11)	(2.06)		

Notes: Standard deviation in parenthesis.

** Significant at the 0.05 level. *** Significant at the 0.01 level.

versus the English auctions. A more complete measure of efficiency would take this effect into account.

Finally, the asymmetric nature of the FPSB auctions with the externality results in substantially lower efficiency compared to the FPSB control auctions (63.7% vs 88.4%, $p < 0.01$). The FPSB control auctions are significantly more efficient than the clock auctions as well ($p < 0.05$).

3.3 Proportion of Auctions Won by Es

Table 2 reports the proportion of auctions won by Es. *Consistent with the prediction, entry is significantly greater in the English auctions than in the FPSB auctions at better than the 5% level.* Thus, to the extent one can draw policy implications from the present experiment, our results indicate that if policy makers want to encourage entry they should adopt the FPSB auction rather than the clock auction.