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TO SPIN OR NOT TO SPIN? NATURAL AND LABORATORY EXPERIMENTS FROM *THE PRICE IS RIGHT**

Rafael Tenorio and Timothy N. Cason

The Wheel is a sequential game of perfect information played twice during each taping of the television game show *The Price is Right*. This game has simple rules and the stakes are high. We derive the unique subgame perfect Nash equilibrium (USPNE) for *The Wheel* and test its predictive ability using data from both the television show and laboratory plays of this game. We find that contestants frequently deviate from the USPNE when the decisions are difficult. The pattern of these deviations is (a) largely independent of the stakes of the game, and (b) consistent with a psychological bias of the omission-commission type.

In this paper we use information from a natural experiment originating in the television game show *The Price is Right* to analyse equilibrium behaviour in a sequential game under varying degrees of complexity and changing stakes. *The Wheel* segment in this show presents participants with a sequential game of perfect information with simple rules and expected payoffs in the order of several thousand dollars. In this game, played twice on each showing of *The Price is Right*, three contestants accumulate points by sequentially spinning a wheel with twenty uniform partitions labelled from 5 to 100.[1] Points awarded to a contestant depend on where the wheel stops. In a predetermined order, each contestant has the opportunity to spin the wheel twice, and her score equals the sum of her first and second (if taken) spins. The contestant whose score is closest to 100 without going over wins the game and the right to compete against another contestant in a game called the *Showcase Showdown*, where prizes are worth thousands of dollars. In addition, any contestant scoring exactly 100 points wins a bonus of $1,000 and a chance of winning an extra bonus of either $5,000 (with 10% probability) or $10,000 (with 5% probability).

A contestant's basic strategy in *The Wheel* consists of whether or not to use her second spin. Consider the first contestant. After her first spin, she must decide whether to spin again or be satisfied with her score. Spinning again increases both the contestant's point total and her likelihood of receiving bonus payments. However, the second spin also creates the risk of exceeding

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[1] On *The Price is Right*, the points awarded to contestants on *The Wheel* range from $0.05 to $1.00. For clarity in exposition, we multiply each point total by $100.

100 points and immediately losing the game. The main strategic question we address is: when should contestants use their second spin? In addition, because the contestant's second spin decision is contingent on her first spin, the score she obtained on the first spin crucially affects the degree of difficulty of that decision. More precisely, first spin scores that are relatively close to 5 or 100 lead to straightforward or 'easy' decisions, while first spin scores in the vicinity of 50 or 60 create more 'difficult' second spin decisions.

We derive and fully characterise the unique subgame perfect Nash equilibrium (USPNE) to *The Wheel* and show that bonus payments affect players' strategies in a meaningful way.[2] We then use data from a sample of 282 plays of *The Wheel* from the television programme to evaluate our analytical predictions empirically. Our results show that a significant percentage of contestants playing *The Wheel* make decisions that deviate from USPNE. Furthermore, these deviations (a) occur consistently in the cases in which the second spin decision is difficult, and (b) show a clear bias for failing to spin again when it is optimal to do so, as opposed to spinning again when it is not optimal to do so. Whereas (a) can be attributed to complexity considerations, we relate (b) to psychological biases of the omission/commission type or 'sudden death aversion'.[3]

A question frequently asked in the empirical and experimental literature on games and decision-making is whether the size of the payoffs is an important determinant of subject behaviour. In particular, if discovering an optimal action is costly in some sense (eg, computational complexity, effort), do subjects have the incentive to bear these costs when rewards are relatively small? And, if there is a marginal reward/marginal effort cost tradeoff operating in the background, would we then expect more accurate play as rewards become larger?[4]

To evaluate the impact of payoff stake size and to gain additional insight into behaviour in this game, we conducted a laboratory experiment reproducing the basic conditions present in *The Wheel*. This experiment nicely complements our analytical and empirical findings from the television game for a number of reasons. First, it allows us to generate additional observations, especially on the difficult cases, to analyse the robustness of our findings based on the game show data. Second, because the laboratory environment is devoid of the 'excitement' inherent in the game show atmosphere, it allows us to explore the extent to which this excitement factor matters. Third, in the experiment subjects play a sequence of games against anonymous, randomly changing opponents, which allows us to determine whether choices improve

[2] After the first draft of this paper was completed, we became aware of an August 16, 1993 *USA Today* newspaper article in which Steve Goodman, then a 19-year old junior math major at the University of Dayton, described the optimal strategy for playing *The Wheel* when there are no bonus payments.

[3] See, for example, Kahneman and Tversky (1982), Spranca *et al.* (1991), and Thaler (2000).

[4] Smith and Walker (1993) document two main benefits associated with increasing payoff size in experimental settings: (a) a shift of the central tendency of the data toward predictions of rational models, and (b) a reduction of the variance of the data around predicted outcomes. See also Kachelmeir and Shehata (1992), and Camerer and Thaler (1995).

with experience. By contrast, contestants on the television game show only play *The Wheel* once. Finally, the payoff scale in the experiment is several orders of magnitude below the payoffs in the game show. As such we should be able to ascertain whether stakes have an important impact on player behaviour.

In spite of the differences between the laboratory experiment and the game show, surprisingly, the empirical results are remarkably similar. The rates of incorrect spin decisions are comparable in the two venues, and the deviations from the optimal strategy exhibit the same bias. This provides additional support for the psychological bias explanation of the results rather than a more conventional explanation such as risk aversion. We also observe only very modest improvement over time in the decisions in the lab.

Although *The Wheel* is an artificial game constructed for entertainment, it should interest economists who study human decision-making because it resembles sequential decision problems arising in important economic contexts. More precisely, *Wheel* players must decide whether or not to spin again, just as job (or low purchase price) searchers must decide whether or not to search again, and firm managers must decide whether or not to continue pursuing investment projects following the receipt of new information. The experimental literature on search has generally found that subjects search relatively well (their stopping rules seem to be close to the optimum), but that there is a tendency to search too little (Cox and Oaxaca, 1992; Sonnemans, 1998). Stopping too soon in the search context is similar to our observation that *Wheel* players often times fail to spin again when it is optimal to do so. While some have argued that early termination of search can be attributed to risk aversion, Sonnemans (1998) argues that sub-optimal search strategies cannot be attributed solely to this factor. As evidence he notes that subjects adopt strategies that are dominated by others — in the sense that they have higher mean earnings but equal earnings variance. Likewise, we argue in this paper that deviations from optimal play of *The Wheel* cannot be due only to risk aversion.

We are not the first to use data from television game shows to investigate human decision-making. Gertner (1993) uses data from the bonus round of *Card Sharks* and finds that contestant behaviour follows risk averse patterns. However he also uncovers several instances in which decisions are inconsistent with expected utility maximisation. Metrick (1995) analyses wagers in *Final Jeopardy* (also see Taylor, 1994). Unlike Gertner, Metrick finds that contestants generally display risk neutral tendencies. Metrick also finds that contestants are more likely to use their 'empirical best responses' when their strategic problems are simpler.[5] Due to the subjective nature of the uncertainty in the game that Metrick analyses, it is difficult to establish whether contestants' decisions are consistent with rationality. Bennett and Hickman (1993) conduct

[5] Metrick defines an empirical best response as the contestant's best response to the observed empirical frequency of strategies played by their opponents in a sample of similar games.

an *ex post* analysis of the bids made by the fourth and final bidder in *The Price is Right* auctions and find that many contestants used bidding strategies that did not maximise their probability of winning. In a related study, Berk *et al.* (1996) find that fourth bidders often use sub-optimal strategies, and that simple rules of thumb explain observed bidding patterns better than rational decision theory. Healy and Noussair (2000) report a controlled experiment to study *The Price is Right* auctions and find laboratory behaviour that closely resembles behaviour on the television game show, at least on early trials. We discuss the relationship between *The Price is Right* auction results and our findings later in the paper.

Our study makes several contributions to the game show-based literature. First, in addition to examining decision-making by individual contestants, we are the first to analyse and test equilibrium behaviour in a well-defined game with only limited strategic uncertainty. Second, because the rules of *The Wheel* are straightforward and all contestants should have the same priors about the distribution of uncertainty, our analysis is likely to provide sharper insights into the predictions of rational models.[6] Finally, our integrated use of both empirical and experimental data allows us to analyse the robustness of player behaviour under various conditions surrounding payoffs and the game environment.

1. The Show and *The Wheel*

The Price is Right is a one-hour television game show that airs five days a week. While contestants are chosen from the audience based on a brief interview conducted as they enter the studio, they are not informed of their selection until the show's announcer calls their names. Four people are initially selected to come to the front of the stage known as 'contestant's row'. An auction is then held in which each contestant bids on a prize. The contestant whose bid is the closest to the suggested retail value of that prize without overbidding wins both the prize and the right to play a pricing game. After the pricing game ends, the process repeats itself with a new individual being invited to contestant's row.

During each *Price is Right* show six auctions and six pricing games are played. *The Wheel* is played twice, once after the third pricing game and again after the sixth. The three auction winners take turns spinning a wheel divided into 20 equal partitions numbered non-sequentially and ranging from 5 to 100. Contestants spin in ascending order of their total winnings before *The Wheel*, and each is given the option of spinning the wheel twice. With each spin of the wheel a contestant accumulates a point total which depends on where the wheel stops. The second (third) contestant does not spin until the first (second)

[6] In addition, the expected payoffs associated with winning *The Wheel* are higher than the expected payoffs associated with winning other games studied before. Comparisons with previous studies reveal the stakes in *The Wheel* are roughly three times those in *The Price is Right* auctions, four times those in the *Card Sharks* bonus round, and 30% higher than the stakes in *Final Jeopardy*.

contestant has exhausted her options. The contestant whose point total is closest to but not more than 100 wins *The Wheel* and an opportunity to compete in the *Showcase Showdown*. Moreover, any contestant who amasses a point total of 100 during *The Wheel* wins \$1,000 and the right to play a game offering a 10% chance of winning \$5,000 and a 5% chance of winning \$10,000. If there is only one contestant with the point total closest to 100 without exceeding it, the game ends after the third contestant finishes her turn. If there is a tie each contestant in the tie spins the wheel once. This tie-breaking procedure is repeated until a winner emerges. In the *Showcase Showdown*, the winner from each of the two segments of *The Wheel* bids on her own showcase, which contains prizes such as trips, automobiles, etc. The contestant whose bid is closest to the suggested retail price of her showcase without going over wins the game and keeps her showcase. If both *Showcase Showdown* contestants overbid neither of them wins anything. If the winner's bid is within \$100 of the actual value she wins both showcases.

2. A Game Theoretic Model of *The Wheel*

2.1. *General Setup*

We assume that each contestant in *The Wheel* (a) understands the rules of the game, (b) is capable of evaluating all of her options, and (c) is risk neutral.[7] Let a_i and b_i represent the number of points received by Contestant i ($i = 1, 2, 3$) on her first and second spin, with $b_i = 0$ if no second spin is taken.[8] Contestants are not awarded any points unless the wheel completes a full rotation. This together with the non-systematic point ordering on the wheel should preclude manipulative behaviour.[9] Thus we assume the wheel is unbiased: a_i, b_i ~ iid Discrete Uniform $\{5,10,\ldots,100\}$. We let $t_i = a_i + b_i$ represent the total number of points accumulated by Contestant i and define x_i to be the point total that Contestant i must acquire to have a chance of winning *The Wheel*. Namely,

$$x_1 = 0,$$
$$x_2 = t_1 I_{\{t_1 \leq 100\}},$$

and

$$x_3 = \text{Max}\{t_1 I_{\{t_1 \leq 100\}},\ t_2 I_{\{t_2 \leq 100\}}\},$$

where $I_{\{t_i \leq 100\}}$ is equal to 1 if $t_i \leq 100$ and zero otherwise.

[7] The risk neutrality assumption is innocuous when no bonus payments are made if contestants are expected utility maximisers. This is because all of the decisions contestants make either increase or decrease their probability of winning a fixed prize. Risk aversion potentially affects decisions only when bonus payments are introduced (see Section 2.3).

[8] We refer to the contestant who spins first as Contestant 1, the contestant who spins second as Contestant 2, and the contestant who spins third (and last) as Contestant 3.

[9] It is uncertain whether contestants actually believe they can manipulate the wheel, but we think such beliefs are unlikely for two reasons. First, we later show that our sample of 846 initial wheel spins (Table 2) yields an empirical distribution that is uniform. Second, if subjects (strongly) believed they could manipulate the wheel, such beliefs should lead to overspinning, rather than the underspinning relative to the equilibrium that we observe.

For simplicity we also assume that when a contestant is indifferent between using her second spin and going to a tie-breaking spin-off she uses her spin. Finally, let $E_i(S)$ represent the expected payoff from playing in the *Showcase Showdown,* and assume that $E_i(S) = E(S) > 0$ for all i.[10] For our equilibrium analysis with bonus payments we assume risk neutrality and that $E(S) =$ \$18,109, the average value paid-out in the 141 *Showcase Showdowns* in our sample. Equilibrium is given by the optimal stopping rule for each contestant: if z_i^* is the minimum value for which Contestant i will not spin again, the triplet (z_1^*, z_2^*, z_3^*) defines the equilibrium.

2.2. *Equilibrium without Bonus Payments*[11]

We first characterise Contestant 3's strategy. After Contestant 3 (C3) takes her first spin either $a_3 > x_3$, $a_3 < x_3$, or $a_3 = x_3$. If $a_3 < x_3$, C3 must spin again to have a positive probability of winning. On the other hand, she will always forgo her second spin if $a_3 > x_3$. If $a_3 = x_3$, C3's second spin decision depends both on the number of contestants tying her score and on the score itself. If there is a two-way tie, C3 will use her second spin if $a_3 = x_3 \leq 50$ because this gives her a better than 50% chance of winning. Along the same lines, in the case of a three-way tie C3 will spin again only if $a_3 = x_3 \leq 65$.

Given C3's strategy, we now focus on Contestant 2 (C2). After C2's first spin, either $a_2 < x_2$ or $a_2 \geq x_2$ If $a_2 < x_2$, C2 must spin again. On the other hand, if $a_2 = x_2$, C2 will not spin again if $a_2 > 65$, a score that is high enough to give her a good chance of beating C3 but too high to risk self-elimination by trying to break the tie with C1. Finally, if $a_2 > x_2$, C2 does not necessarily relinquish her second spin since she wants to give herself the best chance of beating C3 while keeping her probability of self-elimination low. We find, using numerical methods, that when, $a_2 > x_2$, C2 maximises her probability of winning *The Wheel* by relinquishing her second spin when $a_2 >$ 55.[12] That is, $z_2^* = 55$.

[10] This is consistent with our risk neutrality assumption. For notational simplicity, we also assume that $E_i(S) = E(S)$ for all i when there are no bonus payments. With bonus payments, we show that there exists a non-empty set where $E_i(S)$ must belong for all i in order for our results to hold. We then show that this assumption is not crucial.

[11] The solution we describe in this section is an exact solution to this game based on numerical methods. It is not an approximation. We present an analytical solution to a continuous version of *The Wheel* in Appendix A. The presence of ties, bonuses, and discrete partitions, make a complete analytical solution to the actual *Wheel* game extremely difficult to calculate. As mentioned in footnote 2, an undergraduate student at the University of Dayton named Steve Goodman derived the solution to this game independently from us. His solution is for the game without bonus payments. Although Mr. Goodman's solution is identical to ours, we do not know what methodology he used to derive it.

[12] The numerical computation proceeds as follows. There are twenty possible point totals attainable with each spin of the wheel, and during normal play there are at most six spins. Hence, there are sixty-four million (20^6) equally likely permutations of the points generated by the sequence of six spins of the wheel. For instance, the probability (payoff) that C2 wins (expects from winning) *The Wheel* when she sets $z_2 = 50$, Contestant 1 sets $z_1 = 50$, and C3 plays optimally is calculated by determining the percentage of the total permutations C2 wins under these circumstances. Payoffs are evaluated for every possible strategy combination in order to identify the equilibrium strategies. All computer programs are available from the authors. Details of the computer program logic are in Appendix B.

We now characterise Contestant 1's (C1's) strategy. Since C1 spins the wheel first, her minimum score to win is $x_1 = 0$. As with C2, this does not necessarily imply that C1 forfeits her second spin. Our numerical program shows that given the other players' strategies z_2* and z_3*, C1 maximises her probability of winning by relinquishing her second spin if $a_1 > 70$. This implies $z_1^* = 70$, which leads to:

PROPOSITION 1. *When no bonus payments are made, there exists a unique subgame perfect Nash equilibrium* ($USPNE_{NB}$) *to* The Wheel *given by the following strategy profile:*

Contestant 1 *spins again if she gets* 65 *or fewer points on her first spin.*
Contestant 2 *spins again if she gets* 50 *or fewer points on her first spin, if she gets* 65 *or fewer points on her first spin and her score equals Contestant* 1'*s score, or if failing to utilise her second spin guarantees losing.*
Contestant 3 *spins again if she gets* 50 *or fewer points on her first spin and ties one other contestant, if she gets* 65 *or fewer points on her first spin and ties the two contestants, or if failing to utilise the second spin guarantees losing.*
In $USPNE_{NB}$ *Contestant* 1 *wins* 30.82% *of the time, Contestant* 2 *wins* 32.96% *of the time, and Contestant* 3 *wins* 36.22% *of the time.*

Because contestants are just concerned with maximising their probability of winning and playing in the *Showcase Showdown*, $USPNE_{NB}$ is independent of the expected payoff associated with winning *The Wheel*. Additionally, the specific values of z_i* reflect the fact that the wheel's partitions are discrete. See Appendix A for an algebraic solution to *The Wheel* in the continuous no-bonus case.

2.3. *Equilibrium with Bonus Payments*

We now introduce bonus payments in the game so that it mirrors *The Wheel* as played on *The Price is Right*. Any contestant who amasses a score of 100 during her regular turn or spins a 100 in a spin-off receives $1,000 and one bonus spin. If that contestant spins 100 in her bonus spin she wins $10,000, and if she spins either 5 or 15 (the two values on either side of 100), she wins $5,000. Any contestant can win the $1,000 bonus and the bonus spin only once. Intuitively, introducing bonus payments may increase a contestant's incentive to use her second spin. This is because amassing 100 points not only guarantees participation in the *Showcase Showdown*, but also has value in itself. Thus bonus payments potentially make the down side of using the second spin less onerous than in the no-bonus case.

To understand the impact of bonus payments, consider first C3's problem. If bonus payments are large relative to E(*S*), her use of the second spin will be motivated both by the prospect of playing the *Showcase Showdown* as well as getting the bonuses. On the other hand if bonus payments are small relative to E(*S*), her decision about using her second spin is solely driven by the goal of getting to the *Showcase Showdown*, just as in the no-bonus case. As a result since expected bonus payments are fixed, there must be a lower bound on

E(S), denoted E($\underline{S}$), above which C3 will switch from a decision rule partially motivated by bonus payments to a rule exclusively based on maximising the probability of participating in the *Showcase Showdown.*[13]

We derive the lower bound E($\underline{S}$) by considering the case where C3 is most likely to spin again after having won *The Wheel* ($a_3 = 5$, $t_1 > 1$, and $t_2 > 1$). If C3 spins again she has a 5% chance of winning $1,000 and a bonus spin worth an additional $1,000 in expected value. On the down side, there is a 5% chance that she will exceed 100 points and go to a three-way spin-off with C1 and C2. Thus E($\underline{S}$) must be such that:

$$\text{E[payoff forfeiting } 2^{nd} \text{ spin}|a_3 = 5 > x_3] = \text{E[payoff using } 2^{nd} \text{ spin}|a_3 = 5 > x_3].$$

We find that E($\underline{S}$) = $6,315.79 ensures this condition holds.[14] For the remainder of the paper we assume this lower bound for E(S). The value of the prizes routinely awarded in the *Showcase Showdown* are nearly triple this level on average (see Table 1) and *Showcase Showdown* players have roughly a one-half chance of winning the *Showdown*, so this assumption has no bearing on the interpretation of our results.

Given E(S) > E($\underline{S}$), C2 will base her strategy on the conjecture that C3 will follow the same subgame perfect strategy as in the no-bonus case. This does not imply that bonus payments do not impact C2's decision, because if these payments are sufficiently large relative to E(S), C2 could become more aggressive with respect to using her second spin. In fact only if E(S) is sufficiently large relative to bonus payments will C2's optimal strategy be the same as in the no-bonus case. We find that an upper bound on E(S), denoted E($\bar{S}$), exists beyond which E(S) is so large that C2's optimal strategy is unaffected by bonus payments. This upper bound is E($\bar{S}$) = $27,104. Consequently, unlike in the no-bonus case, we find that given C3's strategy and E(S) $\in$ [E($\underline{S}$), E($\bar{S}$)], C2 maximises her expected payoff by not using her second spin if $a_2 > 60$; ie, $\hat{z}_2 = 60$. That is, the bonus payments marginally increase C2's spin threshold.

Finally, our calculations show that given the strategies of C3 and C2 and the assumed bounds on E(S), C1 maximises her expected payoff by not using her second spin if $a_1 > 70$. This is, $\hat{z}_1 = 70$. Note that because of the discrete distribution of points, unlike $\hat{z}_2$, $\hat{z}_1$ is unaffected by bonus payments. This leads to:

[13] Contestants' decisions may potentially be influenced by risk aversion in this case. Take for instance C3, and assume she amasses enough points to win *The Wheel* (ie, $a_3 > x_3$). At this point the spin/no spin decision turns into a choice between playing the *Showcase Showdown* for sure and a gamble where she plays the *Showcase Showdown* and gets the bonus with probability $q < 1$, and gets zero with probability $(1 - q)$. Given the relative magnitudes of the expected payoffs associated with the contestants' decisions, our risk neutrality assumption does not appear onerous. Kachelmeir and Shehata (1992) and Metrick (1995) show that individuals tend to display risk neutral preferences when potential payoffs are large and the probability of attaining those payoffs is reasonably high, as is the case in *The Wheel.*

[14] By certainty equivalence, if C3 was risk averse, E($\underline{S}$) would be lower. As a result, bonus payments would become even less important in influencing C3's decisions.

Table 1

*Descriptive Statistics**

Panel A: Contestant winning percentages on *The Wheel*

Contestant	Winning percentage
1	30.14
2	34.04
3	35.82

Panel B: Dollar value of prizes won by winner of the *Showcase Showdown*

Average	$18,109
Standard Deviation	$8,761
Minimum	$0†
Median	$18,150
Maximum	$50,682

Panel C: Bonus payments made to contestants in *The Wheel*

Payment	Frequency of payment
$1,000	56
$5,000	6
$10,000	7

Panel D: Dollar Prizes Won by Contestants Prior to *The Wheel*

	Auction		Pricing game		Auction and pricing game	
Contestant	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1	1,000	417	521	1,276	1,521	1,371
2	1,154	417	2,700	2,794	3,854	2,763
3	1,116	419	9,572	8,200	10,687	8,169

Notes: * The sample period is from June 1994–March 1995, during which time 141 different broadcasts of *The Price is Right* were recorded. Since *The Wheel* is played twice per broadcast, our sample consists of 282 observations of *The Wheel*.
† No one won the *Showcase Showdown* 8.5% of the time.

PROPOSITION 2. *When bonus payments are made and* $\mathrm{E}(S) \in [\mathrm{E}(\underline{S}), E(\bar{S})]$, *the unique subgame perfect Nash Equilibrium to* The Wheel ($\mathrm{USPNE_B}$) *is identical to* $\mathrm{USPNE_{NB}}$ *with one exception*:

> Contestant 2 *spins again if she gets* 55 *or fewer points on her first spin, if she get*s 65 *or fewer points on her first spin and her score equals* Contestant 1'*s score, or if failing to utilise her second spin guarantees losing.*

In $\mathrm{USPNE_B}$ *Contestant* 1 wins 30.86% *of the time, Contestant* 2 *wins* 32.95% *of the time and Contestant* 3 *wins* 36.19% *of the time.*

Comparing Propositions 1 and 2, we see that when $\mathrm{E}(S) \in [\mathrm{E}(\underline{S}), \mathrm{E}(\bar{S})]$, introducing bonus payments changes the equilibrium strategy profile and slightly improves C1's probability of winning. This is because bonus payments make C2 more aggressive in using her second spin. Thus C2 trades-off a higher probability of winning the bonus for a higher frequency of self-elimination, with C1 being the primary beneficiary of the latter effect.[15] While C1 wins slightly more often at the expense of C2 and C3, it is not surprising that the expected payoffs of all three contestants are higher when bonus payments are introduced. Note also that our assumption that $E_i(S) = E(S)$ for all i, is not crucial for the results. All we need for the equilibrium described in Proposition 2 is that $E(S) \in [E(\underline{S}), E(\bar{S})]$. Finally, if $E(S) > E(\bar{S})$ then $USPNE_B$ is identical to $USPNE_{NB}$, whereas if $E(S) \rightarrow 0$, $\hat{z}_i \rightarrow 100$ for all contestants.

3. Empirical Analysis

3.1. *Data*

Game Show. We obtained our original sample from 141 tapings of *The Price is Right* televised on CBS from June 1994 to March 1995.[16] Since *The Wheel* is played twice on each show, we have 282 observations in our game show sample. Table 1 contains descriptive statistics. Of the 282 winners of *The Wheel*, 129 went on to win the *Showcase Showdown*. Bonus payments of $1,000 were awarded to 56 of the 846 individuals in the sample. Of these 56 individuals, six won $5,000 and seven won $10,000 on their bonus spin. Although seven $10,000 winners is unusually high for 56 bonus spins, the sample size is insufficient for a reliable Pearson Chi-squared test for the overall distribution of bonus spins shown in Table 1C.

Table 1, Panel D also shows the dollar value breakdown of the cash and prizes won by Contestants 1, 2 and 3 in the auctions, in the pricing games, and in total.[17] While there is little deviation in the average value of the prizes won by the contestants in the auction, there are significant differences in the average value of the prizes won in the pricing games. In these games C1 won an average of $54, C2 won an average of $2,700, and C3 won an average of $9,572, in cash and prizes. The large deviation in this dollar value of prizes is a consequence of the winnings-priority scheme used to classify these contestants. Because luck plays a key role in the pricing games and because those games involve completely different skills, it is unlikely that the more successful pricing game contestants are better at the strategic thinking required in the *Wheel*.

Table 2 contains the frequency with which each point total is attained for the 846 first spins by each contestant during regular play of *The Wheel*. We are

[15] These results are due to the discrete distribution of points awarded to *The Wheel* contestants. If points were continuously distributed on [0, 100], the stopping rules of all contestants would change.

[16] The shows in our sample were recorded using a VCR. Some gaps in the sample are due to preemption by breaking news events, such as the O.J. Simpson trial. Repeated attempts to obtain information directly from the show's producers were unsuccessful.

[17] As mentioned in Section 1, the pricing games are played individually by winners of the auction game, prior to play of *The Wheel* later in the television programme. The programme includes dozens of different pricing games that vary from day to day.

Table 2

Distribution of Points Awarded on the First Spin of The Wheel *for All Television Show Contestants of* The Wheel (846 spins)

Points	Frequency (%)	Points	Frequency (%)
5	4.85	55	5.44
10	4.96	60	4.85
15	4.96	65	4.85
20	5.20	70	5.20
25	3.55	75	5.91
30	5.56	80	4.96
35	4.02	85	6.26
40	6.50	90	4.37
45	4.37	95	4.26
50	5.79	100	4.14

Note: The null hypothesis that this distribution is a discrete uniform distribution cannot be rejected at the 90% significance level ($\chi^2_{19\text{d.f.}} = 18.82$).

unable to reject the hypothesis that this sample is drawn from a discrete uniform distribution.[18]

Laboratory Experiment. As a way of complementing the television show data set, we designed and implemented a laboratory experiment reproducing the basic strategic problem faced by *The Wheel* contestants. A total of 69 subjects participated in the experiment, and each subject played *The Wheel* game 30 times. Four sessions were conducted, with the number of subjects varying between 12 and 21 per session. Subjects were randomly regrouped each period for new plays of the game, so they typically faced new opponents each period. Subjects interacted through a computer network, so no subject knew when he or she was grouped with any other specific subject (ie, identification numbers were never displayed). This design permits learning but minimises any potential repeated game effects that could arise, for example, if subjects played against the same players in each game. The order of play was also randomly determined each period.

All sessions had rules exactly as in *The Price is Right*, including the bonus spins for amassing the point total of exactly 100. Instructions are included in Appendix C. Payoffs in the laboratory were scaled down from the game show by a factor of 5,000 to 1. For example, the winner of *The Wheel* game earned $1.80, instead of approximately $9,000 (in expected value) from participating in the *Showcase Showdown*; and the initial bonus for achieving a

[18] The 551 second spins during regular play are not quite uniformly distributed, with spins of 20, 60, 80 and 85 all occurring about 7% (rather than 5%) of the time, and spins of 65 and 70 occurring about 3% of the time. There does not seem to be a pattern to these deviations from uniformity that is consistent with attempts by players to manipulate the spin outcomes, since some of the more frequent outcomes are located next to the less frequent outcomes on the non-sequential number ordering of the wheel. It is possible that the distribution of second spins is not uniform because in this case the wheel starting point (the first spin of those who did not choose to stop) is not random; instead, it is the result of an endogenous decision.

spin total of 100 was \$0.20 rather than \$1,000. Sessions lasted about one hour and subjects earned an average of \$19.42, with a maximum of \$29.50 and a minimum of \$4.00.

In the first two sessions (with 18 and 21 subjects each), as in the game show, all wheel spins were drawn independently and uniformly from the set {5, 10,..., 95, 100}. In the third session (Session 3 with 12 subjects) the first wheel spin of each game was drawn independently and uniformly from the set {55, 60, 65}. All other spins of a game were from the set {5, 10,..., 95, 100} as usual. This was, of course, explained in the instructions. This restricted set of spins at the very beginning of the game does not change any of the analysis of optimal player strategies, but it does allow us to gather more data in the 'difficult' range of opening spin draws.

In the final session (Session 4 with 18 subjects) we removed the first player, so subjects played a two-person version of *The Wheel.* The first wheel spin of each of these two-person games was drawn independently and uniformly from the set {50, 55, 60}. All other spins of a game were from the set {5, 10,..., 95, 100} as usual. Again, this change in the distribution of the first spin does not change the analysis of the game, but it generates more data in the difficult spin total range for Contestant '2' (here actually the first player of this two-person game). These four laboratory sessions provide data on 775 plays of the game.

3.2. *Results*

We first analyse the extent to which Contestants 1, 2 and 3 make decisions consistent with $USPNE_B$. Table 3 shows the instances each contestant took actions inconsistent with those in Proposition 2. Panel A displays the correct utilisation rate for the television game show, and the lower panels display this same information for the laboratory experiment. Panel C is for the laboratory session with the first spin a_1 drawn from {55, 60, 65} and Panel D is for the laboratory session with two contestants and the first spin a_2 drawn from {50, 55, 60}.

With a few minor exceptions, C3's decisions are fully consistent with $USPNE_B$. Nearly all of C1's decisions are consistent with $USPNE_B$ when $a_1 \in \{5, \ldots, 45, 70, \ldots, 100\}$. When $a_1 \in \{50, 55, 60, 65\}$, however, several of C1's decisions deviate from $USPNE_B$. For example, on the game show C1 correctly used her second spin 19 of the 21 times she scored 50 on her first spin but only 3 of the 14 times she scored 65 on her first spin.[19] In the laboratory experiment the incorrect utilisation rates also generally increase as

[19] The percentage of incorrect decisions made by C1 after accumulating 65 points on the first spin is significantly greater than (a) the percentage of incorrect decisions made by C1 after accumulating 50 points (Fisher's Exact Test p-value < 0.001), and (b) the percentage of incorrect decisions made by C1 after accumulating 55 points (Fisher's Exact Test p-value $= 0.017$). The percentage of incorrect decisions made by C1 after accumulating 60 points on the first spin is significantly greater than the percentage of incorrect decisions made by C1 after accumulating 50 points (Fisher's Exact Test p-value $= 0.019$).

Table 3

The Decisions of Contestants 1 and 2 on The Wheel

Panel A: Game Show

	Contestant 1			Contestant 2*		
First spin	Frequency	Correct utilisation of second spin†	Percent correct	Frequency	Correct utilisation of second spin	Percent correct
{5, …, 30}	81	81	100	14	14	100
35	13	13	100	4	3	75
40	14	14	100	4	3	75
45	12	12	100	3	3	100
50	21	19	90	4	3	75
55	11	8	73	6	3	50
60	15	8	53	8	6	75
65	14	3	21	7	7	100
{70, …, 100}	101	101	100	77	77	100
Total	282	259		127	119	

Panel B: Lab Experiment (Sessions 1 and 2; same spin range as the game show)

First spin	Frequency	Correct utilisation of second spin	Percent correct	Frequency	Correct utilisation of second spin	Percent correct
{5, …, 30}	111	111	100	31	31	100
35	28	28	100	8	7	88
40	28	28	100	4	3	75
45	17	16	94	8	7	88
50	16	15	94	1	0	0
55	23	19	83	12	6	50
60	22	11	50	11	5	45
65	15	9	60	5	5	100
{70, …, 100}	126	122	97	97	97	100
Total	386	359		177	161	

Panel C: Lab Experiment (Session 3, which had first spin drawn from {55, 60, 65})

First spin	Frequency	Correct utilisation of second spin	Percent correct	Frequency	Correct utilisation of second spin	Percent correct
{5,…,30}	0	0		11	11	100
35	0	0		5	5	100
40	0	0		3	3	100
45	0	0		2	2	100
50	0	0		3	3	100
55	41	40	98	2	2	100
60	39	30	77	4	4	100
65	40	22	55	3	3	100
{70, ..., 100}	0	0		44	41	93
Total	120	92		77	74	

Panel D: Lab Experiment (Session 4, which had 2 contestants and first spin drawn from {50, 55, 60})

First spin	Frequency	Correct utilisation of second spin	Percent correct	Frequency	Correct utilisation of second spin	Percent correct
50				86	81	94
55				87	51	59
60				96	62	65
Total				269	194	

Notes: * We only consider those instances in which Contestant 2 does not have to spin again to have a chance to win. † We define a decision as correct if it corresponds to the unique subgame perfect Nash equilibrium derived in Proposition 2. On the Game Show there were 7 instances in which Contestant 3 tied the highest score with her first spin. All of these ties were two-way ties. In each of these instances, Contestant 3 correctly utilised her second spin. In the Laboratory Experiment there were 30 instances in which Contestant 3 tied the highest score with her first spin. All of these ties were two-way ties. In 26 of these 30 instances, Contestant 3 correctly utilised her second spin. All four violations were when Contestant 3 incorrectly spins again—three times when her first spin was 55 and one time when her first spin was 60.

the first spin rises when $a_1 \in \{50, 55, 60, 65\}$. C2 also made several decisions violating $USPNE_B$ in both the game show and in the laboratory experiment. These errors were most common when $a_2 \geq x_2$ and $a_2 \in \{50, 55, 60,\}$.[20] Nevertheless, players clearly do not use a simple, naïve average rule such as 'spin again if my first spin is no greater than 50, since the expected value from a spin is 50'. They also respond to the strategic properties of the game, since C1 spin rates generally exceed C2 spin rates as predicted by the equilibrium analysis.[21]

Table 3 pools all of the choices across participants. Each contestant played the game once on the game show, so the game show observations are statistically independent. But in the laboratory experiment subjects played the game repeatedly, so it is inappropriate to pool multiple choices by the same subject for statistical tests that require independence across observations. Therefore, for the following statistical tests we include only one observation per subject. To be consistent with the experience level of the game show participants, we include only the first time that each subject faced the particular choice being analysed.[22] In what follows we pool the data across all four laboratory sessions, because a series of Fisher's Exact Tests conducted separately for each first spin never indicate that the correct spin utilisation rate is different across laboratory sessions at the 10% significance level.

Table 4 presents a comparison of the game show and laboratory data based on the first time that the game show and laboratory subjects faced the 'difficult' first spins. About one-third to one-half of C1's fail to spin a second time when their first spin is 60 or 65, except for game show contestants who usually fail to spin when their first spin is 65. The only significant difference between behaviour on the game show and in the laboratory experiment occurs when C1 obtains 65 on her first spin; for all other Fisher's Exact Test comparisons the p-values exceed 0.32. The small sample sizes for C2 on the game show cause the statistical tests to have low power, but both the lab and game show data exhibit the same pattern. The correct use rate is lowest (about 50%) when C2's first spin is 55, because C2 often fails to spin again. The correct use rate increases when C2's first spin is 60, because in this case she should not spin again except when she is tied with C1's total. That is, in all cases the deviation from optimal

[20] Despite the multiple violations of $USPNE_B$ the distribution of winning percentages across contestants in our game show sample is statistically indistinguishable from the analytical distribution in Proposition 2 ($\chi^2 = 0.0153$ versus $\chi^2_{0.25}(2) = 2.77$). We must remark however that this result has no power and is mainly driven by the large number of instances in which the contestants' decisions were straightforward.

[21] For example, according to Proposition 2, C2 should not spin again when her first spin totals 60 and she is not tied with C1; C1, however, should always spin again when his first spin totals 60. In the laboratory data, the first time individual players encountered these conditions C1 spun 18 out of 29 times (62%) while C2 spun 11 out of 31 times (35%). These spin rates are significantly different (Fisher's Exact Test p-value = 0.035).

[22] As an anonymous referee notes, although players in the game show only play *The Wheel* game once, they may have observed the game and thought about their strategies numerous times. In that sense, they may be more 'experienced' than some of the laboratory players.

Table 4

Comparison of Correct Utilisation Rates for the Game Show and the Laboratory Experiment, Including Only the First Time Each Subject Faced Each Particular Choice

	Contestant 1			Contestant 2		
	Correct use	Incorrect use	Total	Correct use	Incorrect use	Total
First Spin = 50						
Game show	19	2	21	3	1	4
Laboratory experiment	14	0	14	19	2	21
	Fisher's	Exact Test	p-value = 0.506	Fisher's	Exact Test	p-value = 0.422
First Spin = 55						
Game show	8	3	11	3	3	6
Laboratory experiment	25	3	28	16	15	31
	Fisher's	Exact Test	p-value = 0.323	Fisher's	Exact Test	p-value = 1.000
First Spin = 60						
Game show	8	7	15	6	2	8
Laboratory experiment	18	11	29	20	13	33
	Fisher's	Exact Test	p-value = 0.748	Fisher's	Exact Test	p-value = 0.687
First Spin = 65						
Game show	3	11	14	7	0	7
Laboratory experiment	17	9	26	8	0	8
	Fisher's	Exact Test	p-value = 0.019	Fisher's	Exact Test	p-value = 1.000

Note: All p-values are based on the (two-tailed) null hypothesis that the correct use rate is equal on the game show and in the laboratory experiment.

play occurs most frequently from players failing to spin again when doing so increases the expected payoff.[23]

3.3. *Interpretation*

To gain some insight into the pattern of the deviations from optimal play, in Table 5 we show the expected game show payoffs associated with the

[23] Subjects in the laboratory experiment modestly improved their spin decisions after gaining experience. To document the changes in behaviour over time we compared the correct spin utilisation rates in the first 10 periods and the last 10 periods for the sessions with opening spins drawn from the difficult range (Sessions 3 and 4). In these sessions subjects had a much greater opportunity to learn since they repeatedly made spin decisions in the difficult range – an average of 3 to 5 decisions in the session for each of the difficult opening spins. In Session 3, when C1 faced an initial spin of 60 he correctly utilised his second spin 9 of the 12 times in periods 1–10 (75%), improving to 14 out of 16 times in periods 21–30 (88%). In this same session, when C1 faced an initial spin of 65 he correctly utilised his second spin 5 of the 12 times in periods 1–10 (42%), improving to 7 out of 11 times in periods 21-30 (64%). In Session 4, when C2 (who was actually the first player of this two-player game) faced an initial spin of 55 she did not improve her correct utilisation rate over time (15 out of 24 were correct in periods 1–10, and 20 out of 32 were correct in periods 21–30, both 62.5%). In Session 4, when C2 faced an initial spin of 60 she correctly utilised her second spin 16 of the 34 times in periods 1–10 (47%), improving to 22 out of 28 times in periods 21–30 (79%).

Table 5

Contestant 1 and Contestant 2's Expected Payoffs from Playing The Wheel *Conditional on Correctly Utilising Second Spin* ($)*, †

	Contestant 1		Contestant 2	
First spin	Expected payoff if second spin is properly utilised	Expected payoff if second spin is improperly utilised	Expected payoff if second spin is properly utilised	Expected payoff if second spin is improperly utilised
5	1,981	4	2,056	1,337
10	1,980	13	2,055	1,342
15	1,979	31	2,053	1,350
20	1,976	58	2,049	1,363
25	1,971	97	2,043	1,382
30	1,963	149	2,033	1,411
35	1,952	219	2,019	1,452
40	1,937	311	1,999	1,512
45	1,915	428	1,972	1,595
50	1,887	577	1,936	1,706
55	1,849	759	1,890	1,848
60	1,795	1,075	*2,054*	*1,808*
65	1,721	1,482	2,277	1,746
70	*1,961*	*1,623*	2,562	1,659
75	2,583	1,494	3,087	1,527
80	3,346	1,326	3,764	1,353
85	4,268	1,113	4,608	1,132
90	5,373	844	5,633	855
95	6,683	510	6,853	513
100	10,200	0	10,264	0
Average	2,966	606	3,160	1,345

Notes: * Each contestant's optimal stopping rule, and associated expected payoffs and parameters are in italics.
† All expected payoffs include bonus payments.

equilibrium and non-equilibrium use of the second spin by C1 and C2 conditional on the value of their first spins. We derive the expected payoffs for C1 on the assumption that C2 follows her subgame perfect strategy, and the expected payoffs for C2 are computed excluding the cases where she must spin again to have a chance of winning. From this table, we can see that first spins such as 5 or 100 yield very easy second-spin decisions, in the sense that the expected payoffs from not following the subgame perfect strategy are minuscule relative to the ones associated with equilibrium behaviour. On the other hand, as first spins near their equilibrium stopping values, the problem becomes very difficult. For instance, when C2's first spin yields 55 points, an increment below the critical value, only $42 separates the expected payoffs from correctly and incorrectly using the second spin. A similar scenario arises when C1's first spin value equals 65, where less than $300 separates the correct and incorrect utilisation expected payoffs. In sum, the players' conditional payoff functions appear to be very flat in the vicinity of the equilibrium critical values, which may at least partly explain the higher frequency of mistakes in this range of first spins.[24]

[24] Since the payoffs in the laboratory experiment are 5,000 times smaller than the ones in the game show, the differences in payoffs are 5000 times smaller. At the extreme, the difference in expected payoffs for the marginal case of a first spin of 55 for C2 is less than one cent!

A paradigm that rationalises some of the characteristics of our data is that of Quantal Response Equilibrium (QRE) formalised by McKelvey and Palfrey (1995, 1996, 1998), based on a form of bounded rationality (eg, Rosenthal, 1989). According to QRE, players are not always able to evaluate their expected payoff from following a given course of action perfectly; ie, there is noisy payoff observability. If the accuracy of a player's evaluation of her expected payoff is indexed by a precision or 'rationality' parameter, her ability to select the best response actions will depend on how 'rational' the player is. We believe the basic QRE premise fits *Wheel* decisions fairly well, as it is very likely that contestants can only imperfectly evaluate the expected payoffs associated with any given decision. More precisely, in those *Wheel* cases where the expected payoffs from following and not following the equilibrium strategy are very close (ie, the difficult cases), QRE implies that a contestant would have to be highly rational to choose the payoff-maximising action. In fact, Tenorio *et al.* (1999) estimate that precision parameters necessary to act rationally most of the time (99.9%) are as much as 43 times larger in the difficult than in the easy cases.

Although the noisy expected payoff/QRE approach yields interesting insights into the deviations from equilibrium play, a definitive bias remains. The vast majority of errors both in the game show and lab experiment are of the under-spinning rather than the over-spinning type. That is, when making errors, players mostly fail to spin again when it is profitable to do so, especially when they face a substantial risk of going over 100 and immediately losing the game. For example, contestant one should always spin again when her first spin is 60 or 65, but in these cases game show contestants only spin 38% of the time and laboratory subjects only spin 62% of the time. In contrast, no contestants on the game show and only a very small number of laboratory subjects spun again when their initial spin was 70 or larger. This bias in contestant errors toward incorrectly forfeiting the second spin can be partially explained by the QRE approach (Table 5) in the case of C2, where at the margin, under-spinning has a lower expected cost ($42) than over-spinning ($246). Interpreting the under-spinning bias in this way for C1 is not as straightforward. In C1's case the relative costs of under and over-spinning are more symmetrically distributed around the critical first spin value.[25]

[25] Moreover, the QRE approach posits that error rates depend on expected payoffs, and by design the expected payoffs are 5000 times higher on the television game show than in the laboratory experiment. Error rates should therefore be substantially lower on the game show. As Table 4 demonstrates, however, when controlling for experience the error rates are rarely significantly different in the two venues. An anonymous referee suggests Radner's notion of the Epsilon Equilibrium as a possible alternative model of bounded rationality (Radner, 1980). According to this model, contestants will not bother to switch to an alternative strategy if switching to that strategy nets them expected profits of less than some value epsilon. The roughly equal error rates in the game show and the laboratory experiment suggests that if such a theory were to describe play of this game, the relevant epsilon would need to be proportional to the expected payoffs of the game. Error rates also differ sometimes when the expected payoffs of an error are approximately equal, however, such as for C2's first spin of 50 and 60 (Table 5). As Panel D of Table 3 indicates, error rates are much higher in Session 4 when C2's first spin is 60. Consequently, the pattern of deviations from USPNE does not seem entirely consistent with the epsilon equilibrium.

We believe that a more plausible explanation of participants' failure to spin in marginal conditions is the *omission bias* that is well documented in the psychology literature. When equally bad outcomes can occur through an explicit act (*commission*) or a failure to act (*omission*), many studies indicate that subjects tend to prefer the omission. Hypothetical scenarios that document this bias often involve moral judgements. For example, an actor intends to bring about some harm to someone else, and in various endings of each scenario the actor attempts to bring about the harm either through omission or commission (Spranca *et al.*, 1991). Subjects rate the actor's morality on a scale from 0 (not immoral at all) to –100 (as immoral as possible) in each scenario.

This omission bias is also present in non-moral decisions, however, and may be caused in part by feelings of *regret*, combined with loss aversion, when the reference point is the omission (Kahneman and Tversky, 1982). In some conditions this regret is more salient when people obtain full knowledge of the outcomes that could arise from alternative decisions (Ritov and Baron, 1995). In *The Wheel*, players sometimes learn the consequences of their omissions depending on the spin decisions and outcomes of subsequent players, but they only learn the consequences of their spin if they actually select this option.[26] Another experiment could test this omission bias explanation by framing the subjects' action as *stopping before the second spin*, where the second spin would be the automatic (default) choice if the subject took no action. Omission bias in this alternative design would correspond to overspinning instead of underspinning.

A game similar to *The Wheel* with real monetary consequences of omissions and commissions is the casino game of Blackjack. A player must 'hit' (ie, take more cards) before his opponent (the dealer) does, and he wins if he achieves a higher card total than the dealer not exceeding 21 (or if the dealer's card total exceeds 21). Just as an optimal but risky play in *The Wheel* is for Contestant 1 to spin again when her first spin is 60 or 65, in some circumstances (eg, when the dealer has 10 showing) an optimal but risky play for a Blackjack player is to hit when her current card total is 15 or 16. Keren and Wagenaar (1985) document that Blackjack players exhibit the same omission bias we observe in *The Wheel*: players frequently (about 80% of the time) fail to take a card in these risky circumstances. Keren and Wagenaar suggest several explanations for this common decision error, including a desire to pass control of the ultimate win/lose outcome to the dealer, as well as an incentive to defer the bad news of losing to a later stage of the game (Thaler, 2000, has termed this last explanation 'sudden

[26] Landman (1987) replicates and extends the study by Kahneman and Tversky (1982) and demonstrates that subjects may experience greater *joy* when a good outcome occurs through an action rather than inaction. In *The Wheel*, this would correspond to greater joy when winning by spinning to a high total rather than from unlucky spins of one's opponents. Although the difference is not significant in Landman's experiment, the bias toward action for positive outcomes is smaller than the bias for inaction for negative outcomes. Based on this evidence and other evidence that emotional reactions to negative outcomes are greater than for positive outcomes, she argues that the bias overall would lead to more conservative decision-making. This interpretation is consistent with our *Wheel* data.

death aversion'). These explanations and regret can all lead to an omission bias in *The Wheel*.

A related explanation is that contestants may derive utility from being in the limelight. When a contestant does not self-eliminate, a camera shows a close-up of the contestant standing underneath her *Wheel* score. Thus a preference for being in the limelight in itself gives the contestant an incentive not to spin again. In contrast, when a contestant over-spins and eliminates herself, the contestant walks away and the audience reacts with a loud groan. Self-consciousness about this scenario may further induce under-spinning. We tend to regard this as a less likely explanation for the bias, because a similar pattern prevailed in the lab, where the limelight effect is non-existent.

4. *The Price is Right* Auctions and *The Wheel*

Berk *et al.* (1996), in their study of the auctions conducted six times during each showing of *The Price is Right,* conclude that contestants often use strategies that are 'transparently sub-optimal'. They reach this conclusion based on their analysis of the behaviour of the fourth and final bidder at each auction. It can be shown that fourth bidders must either 'cut-off' (bid $1 above) a previous bid or bid zero to maximise their probability of winning. Yet, in about one-half their sample auctions, the fourth bidder does not follow this strategy. The authors go on to show that bidders (a) appear to use rules of thumb to make decisions, and (b) seem to use previous bids as inputs in their bidding strategies. In related work, Bennett and Hickman (1993) independently derive similar results regarding bidding behaviour in these auctions, and Healy and Noussair (2000) show that the fourth bidders are more likely to use this optimal strategy as they gain experience.

Our analysis of *The Wheel* suggests that contestants make correct decisions in the cases that could be labelled as transparent, while making frequent mistakes in the non-transparent cases. This prompts the following question: why do auction players fail to make the right decision in a transparent problem while *Wheel* players do not? A first possible reason is that the transparent cases at *The Wheel* are considerably easier than the fourth bidder's problem at an auction. Arguably, the decision whether to spin or not after attaining a relatively low or high score on the first spin is an order of magnitude easier than figuring out the cutting-off strategy in an auction. In addition, the error rates in *The Wheel*'s most difficult cases (Table 3) suggest that this problem may sometimes be harder than the fourth bidder's problem. A second explanation may lie on contestant selectivity. To be eligible to play *The Wheel,* a contestant must have won an auction. Bennett and Hickman (1993), and Berk *et al.* (1996) show that contestants that use the optimal auction strategies stand to increase their winning frequencies substantially (roughly by 50%) and thus to go on and play *The Wheel*. As a result the pool of *Wheel* contestants may be selected from a population of more skilled players, ie, players more likely to figure out the rational bidding strategy at the auctions. Unfortunately, we are unable to test this hypothesis empirically because the available data sets do not contain matching samples of contestants playing both games. A third explanation is that players may be reluctant to employ (very publicly) the cutting-off strategy, since it clearly rules out another person from winning and could be perceived as 'mean spirited'.[27] Finally, it is possible that a fourth bidder may intentionally bid sub-optimally at a given auction to delay her possible winning until a later auction. This may result from a bidder's anticipation of playing a pricing game involving a prize of substantially higher than average value (eg, a car as opposed to a couch) later in the show. Such large prizes appear once during each three-auction block in every show.[28]

5. Conclusions

Very seldom a natural experiment arises that allows researchers to examine the predictions of a theoretical model cleanly. *The Wheel*, played twice each airing of *The Price is Right*, is one of those rare cases. This game is a one-shot, sequential game of perfect information with simple rules and a prior source of uncertainty with a known distribution. In addition, the expected payoffs associated with winning *The Wheel* are substantial. We derive the unique subgame perfect Nash equilibrium to *The Wheel* under the basic assumptions implied by the game setup. Using a large sample of plays of *The Wheel*, both from the actual show and a matching laboratory experiment, we find that the decisions made by contestants in *The Wheel* are not always consistent with the unique equilibrium. Our analysis indicates that the frequency with which contestants make decisions inconsistent with equilibrium increases as their problems become more difficult. Furthermore, our results show no significant difference in the pattern of play between the actual show and the laboratory experiments, which suggests that difference in stakes does not play a major role in explaining behaviour in this game. Thus our results favour the view that players' computational ability and decision-making biases are likely to play a more important role than stakes in empirical/experimental games, and as such should be more routinely incorporated into theoretical models.

De Paul University
Purdue University
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Appendix A. Algebraic Solution to *The Wheel* with a Continuous Support and No Bonus Payments

In what follows we present a solution to a stylised version of *The Wheel* when no bonus payments are made. In this version, we keep all of the assumptions outlined in Section 2.1 with the following exception: rather than assuming that

[27] Healy and Noussair (2000) provide some evidence that supports this explanation. They conduct laboratory *Price is Right* auctions with and without subject anonymity in different treatments, and they observe more cutting-off in the anonymous treatment.

[28] Observe that this would introduce a repeated-game ingredient into the auctions.

a_i, b_i ~ iid Discrete Uniform{5, 10, ..., 100}, we now assume a_i, b_i ~ iid Uniform[0, 1]. We concentrate on the two players facing strategically relevant decisions, C1 and C2.

C2's problem:

Let x be the value of C2's first spin that maximises her probability of winning.

(i) When C2 uses her second spin, her score must not exceed 1 to have a chance of winning (ie, $x + b_2 < 1$). When C2's score does not exceed 1, two events may take place: (a) C3 beats her with her first spin (ie, $a_3 > x + b_2$), or (b) C3 must spin twice to have a chance of winning. In the latter case, C2 wins if $a_3 + b_3 > 1$, or if $x + b_2 > a_3 + b_3$.

Hence, the probability of C2 winning is:

$$\Pr(1 > x + b_2 > a_3 + b_3) + \Pr(a_3 + b_3 > 1) - \Pr(a_3 > x + b_2). \tag{1}$$

Let

$$A = \Pr(1 > x + b_2 > a_3 + b_3) = \Pr(1 - b_2 > x > a_3 + b_3) \tag{2}$$

since the x's that are less than $1 - b_2$ must be greater than $a_3 + b_3$,

$$B = \Pr(a_3 + b_3 > 1), \text{ and} \tag{3}$$

$$C = \Pr(a_3 > x + b_2) = \Pr(a_3 - b_2 > x). \tag{4}$$

Since $a_i + b_i$ follows a triangular distribution on [0, 2], and $a_i - b_i$ follows a triangular distribution on [−1, −1], for all i, j, we get:

$$B = \frac{1}{2}, \text{ and} \tag{5}$$

$$C = \Pr(a_3 - b_2 > x) = \frac{(1 - x^2)}{2}. \tag{6}$$

Hence, the probability of C2 winning is

$$A + B - C = \frac{x^2}{2}(2 - x). \tag{7}$$

(ii) When C2 does not use her second spin, two events may take place: (a) C3 beats her with her first spin (ie, $a_3 > x$), or (b) C3 must spin twice to have a chance of winning. In the latter case C2 wins if $x > a_3 + b_3$ or if $a_3 + b_3 > 1$.

The probability of C2 winning is:

$$\Pr(x > a_3 + b_3) + \Pr(a_3 + b_3 > 1) - \Pr(a_3 > x). \tag{8}$$

Let

$$D = \Pr(x > a_3 + b_3) = \frac{x^2}{2}, \tag{9}$$

$$E = \Pr(a_3 + b_3 > 1) = \frac{1}{2}, \text{ and} \tag{10}$$

$$F = \Pr(a_3 > x) = (1 - x). \tag{11}$$

Hence, C2 wins with probability

$$D + E - F = x + \frac{(x^2 - 1)}{2}. \tag{12}$$

But, in equilibrium, C2 should be indifferent between spinning and not spinning again. Thus, from (7) and (12), x should satisfy:

$$\frac{x^2}{2}(2-x) = x + \frac{(x^2-1)}{2}. \tag{13}$$

The only real root to this cubic equation is 0.56984.

C1's problem:

Following the logic used to solve C2's problem, the probability of C1 winning if she uses her second spin is $G + H + I = (y^4/4)(2-y)$, where:

$$G = \Pr(y < 1 - b_1)\ \Pr(y > a_2 + b_2)\ \Pr(y > a_3 + b_3), \tag{14}$$

$$H = \Pr(a_2 + b_2 > 1) - \Pr(a_2 - b_1 > y), \tag{15}$$

$$I = \Pr(a_3 + b_3 > 1) - \Pr(a_3 - b_1 > y), \tag{16}$$

and y is the value of C1's first spin that maximises her probability of winning. The probability of C1 winning if she does not use her second spin is

$$J + K + L = \frac{y^4}{4} + \left(y - \frac{1}{2}\right)^2, \tag{17}$$

where:

$$J = \Pr(y < a_2 + b_2)\Pr(y > a_3 + b_3), \tag{18}$$

$$K = \Pr(a_2 + b_2 > 1) - \Pr(a_2 > y), \text{and} \tag{19}$$

$$L = \Pr(a_3 + b_3 > 1) - \Pr(a_3 > y). \tag{20}$$

Once again, in equilibrium, the critical stopping value for C1 should satisfy:

$$\frac{y^4}{4}(2-y) = \frac{y^4}{4} + \left(y - \frac{1}{2}\right)^2. \tag{21}$$

The only root to this equation in the interval [0, 1] is 0.618.

Appendix B. Logic Underlying Numerical Calculation of Equilibrium

In order to determine the equilibrium strategy for each player, we calculated the expected payoffs to each player for each possible strategy. Given that each player has two spins (although for a given strategy, they may choose to use only one), there are 20^6 or 64 million possible realisations of the wheel game (occurring with equal probability). Therefore, we calculate a player's expected payoff by determining the payoffs associated with each potential realisation and taking a weighted-average across realisations. Having estimated these expected payoffs, we are able to calculate the optimal stopping rule for each player.

More precisely, we can characterise each player's strategy by a set of decision rules of the type:

Player 1:

'If my first spin is greater than or equal to A, *I will not spin again. Otherwise, I will spin again'.*

Player 2's strategy is more complicated since she must also decide what to do in the case of a tie. Thus, her strategy can be characterised by the following:

'If my first spin is less than the "score to beat", I will spin again. If my first spin exceeds the "score to beat" and is greater than or equal to B, *I will not spin again; otherwise I will spin*

again. If I tie with player 1 on my first spin and this spin is less than C, *I will spin again; otherwise, I will not'.*

For player 2, the 'score to beat is defined as the total of player 1's spin(s) or zero if this total exceeds 100.

Player 3's strategy is even more detailed than the other two player's strategies because this player's first spin could result in either a two- or three-way tie. Since ties require a 'spin-off' where each contestant takes one spin and the one with the highest spin goes on to the Showcase Showdown, player 3 may use a different stopping rule for a three-way tie than for a two-way tie. Hence, player 3's strategy can be written as

'If my first spin is less than the "score to beat", I will spin again. If my first spin exceeds the 'score to beat' and is less than D, *I will spin again; otherwise I will not. If I tie with exactly one of the earlier players on my first spin and this spin is less than* E, *I will spin again; otherwise I will not. If I tie with both of the earlier players on my first spin, I will spin again if this spin is less than* F; *otherwise, I will not'.*

We can define the combination of strategies by the set {*A, B, C, D, E, F*}. Given that each element can take on one of 21 different values (ie, values of 0, 5, 10, ..., 100), there are 21^6 different strategy combinations. For a given strategy combination, we calculate the payoff to each player given a realisation of the wheel. A realisation then takes the form of $\{z_{11}, z_{12}, z_{21}, z_{22}, z_{31}, z_{32}\}$, where the first subscript denotes the player and the second denotes the spin. The strategy set is used to determine the payoffs to each player for each realisation of the wheel.

For example, one realisation would be {40, 10, 55, 65, 50, 45}. Let's assume that the strategy set we want to investigate is {70, 60, 50, 50, 60, 65}. The game would unfold as follows. Player 1's first spin is a 40. Given that the stopping rule tells the player to spin again if her first spin is less than 70, she would choose to spin again. The second spin is the second element of the realisation set (10), so player 1's total would be 40 + 10 or 50. Since this is less than 100, the 'score to beat' is set at 50. Next, player 2 spins, and the realisation is 55 (ie, the third element of the realisation set). Since the decision rule is to spin again if the first spin exceeds the score to beat (50) and this spin is less than 60 (ie, the second element of the strategy set), this player will spin again. Her second spin is a 65, for a total of 115. Since this exceeds 100, player two is eliminated and the score of 50 remains the 'score to beat'. Next, Player 3 spins, with the first spin being 50 (ie, the fifth element of the realisation set), which is exactly equal to the 'score to beat'. Player 3's strategy says to spin again if the first spin results in a two-way tie and is below 60. Consequently, player 3 spins again, with the second spin being 45. Since player 3's total (95) is less than 100 and exceeds the previous 'score to beat', player 3 is the winner and receives the expected payoff of going to the Showcase Showdown. The other two players receive a payoff of zero.

Note that scores of 100 result in the player receiving $1,000 cash. Plus, the player receives a bonus spin, where she wins $10,000 with probability 0.05 and $5,000 with probability 0.10. Thus, receiving a score of 100 increases the expected payoff by $2,000. Consequently, in the game above, had player 3's second spin been 50, her total score would have been 100. Thus, her payoff would be equal to the expected value of participating in the *Showcase Showdown* plus $2,000. Further, if player 3's rule would have been to stop at 50 in a one-way tie, then these two individuals would have been involved in a 'spin-off', where each individual gets one spin with the one with the highest spin going on to the *Showcase Showdown*. Thus, in a two-way tie, each individual has a 50% chance of going on to the *Showcase Showdown*, while a three-way tie results in a 33.33% chance. Such spin-offs and bonuses were taken into account in calculating the expected payoffs.

To calculate the expected payoff for the strategy given above, we would calculate the payoff for the remaining possible wheel realisations. The expected payoff for each player for a given strategy is calculated as the average of these 64 million possible payoffs. This is repeated for all the possible strategy sets. What we are left with is the expected payoff to each player for each strategy set, which allows us to determine the subgame perfect Nash equilibrium.

It is important to note again that we do not calculate the expected payoffs by simulating a large number of games and then using those outcomes to calculate some form of central tendency measure. Instead, we calculate the exact payoffs accrued by each player in each state, and then take a probability-weighted average across states to get the actual expected payoff. As such, since our algorithm looks for a decision rule that leads to a maximum among these expected payoffs, our solution is an exact solution.

Appendix C. Experiment Instructions

General

This is an experiment in the economics of decision making. The instructions are simple and if you follow them carefully and make good decisions you will earn money that will be paid to you in cash at the end of the experiment.

During the experiment you will interact in a sequence of 30 decision 'periods' in groups of three persons. The total number of participants in this experiment today is —. The computer will randomly reassign you into groups of three persons each period. Everyone has an equal chance of being assigned with any other two participants. The computer will also randomly determine the order in which the three players in each group will take turns making decisions. Therefore everyone has an equal chance at being the first, second, or third player to make a decision within each group. All of these assignments are totally random and are not affected by any decisions anyone makes during the experiment. You will never learn the identity of the persons you are assigned with in any period.

The Wheel

As described in a moment, you will decide each period if you want to make either one or two 'spins' of a 'wheel'. These spins are the outcome of a random process that will actually be determined by a random number generator on the computer. But to understand the spin process consider the wheel that the experimenter is showing around the room. This wheel has 20 segments. Each segment is labelled with a number, from 0.05 to 1.00. Each 5-cent increment is included on the wheel, and all segments are the same size. Therefore, each spin of the wheel gives you an equal chance of the outcomes 0.05, 0.10, 0.15,…, 0.95, 1.00.

Decisions

Your total spin score is the sum of your one or two spins of the wheel. During each period everyone will make one decision: whether or not to spin the wheel a second time to increase their total spin score. The objective is simple—obtain the highest total spin score of the group of three persons without going over 1.00. Anyone who has a total spin score greater than 1.00 automatically loses that period. The winner is the person with the highest total spin score that is less than or equal to 1.00, and that winner receives $1.80 in cash. There will be one winner each period in each group of three.

Ties

In the event that more than one participant in each group of three persons has the same, highest spin score without going over 1.00, the computer will conduct a 'spin-off' to determine the winner. In this spin-off, each tied participant gets one spin of the wheel. The person who spins the highest number wins the $1.80 that period. (If the spin-off spins are tied as well, additional spin-off rounds are conducted until a single winner emerges.)

Bonuses

If you obtain a total spin score of 1.00 you instantly win a bonus of $0.20. By obtaining this total spin score of 1.00, you also get one (and only one) extra free spin that does not count in your total spin score. If this extra free spin comes up 1.00, then you win another bonus of $2.00, for a total bonus of $2.00 + 0.20 = $2.20. This is in addition to the $1.80 that you will probably win for having the highest total spin score. If this extra free spin comes up either 0.05 or 0.10, then you instead win another bonus of $1.00, for a total bonus of $1.00 + 0.20 = $1.20. Note that when you obtain a total spin score of 1.00 you have 1 chance out of 20 to receive the total bonus of $2.20; you have 2 chances out 20 to receive the total bonus of $1.20; and you have 17 chances out of 20 to receive the total bonus of $0.20.

Procedures

Everyone makes at least one spin, so the computer automatically displays the outcome of the first spin before asking you for a decision. You should look at the outcome of your own first spin, as well as the total spin scores of any participants who have already made their decisions. You then check off either the Stop Here button or the Spin Again button, and then click on the larger button marked Continue. Spin outcomes and total spin scores are displayed to all three members of your group. At the end of the period you should record any earnings you have for that period, including bonuses, on your Personal Record Sheet. The winner of each group is noted at the bottom of your decision frame, and your player number for that period is highlighted in red. That is how you can quickly determine if you are the winner that period.

Summary

- You will be randomly reassigned each period into groups of three. The decision order is also random.
- On any wheel spin the numbers 0.05, 0.10,…, 0.95, 1.00 are equally likely.
- Each participant decides whether to stop at one spin or spin a second time. Only one or two spins are possible. The total spin score is the sum of the one or two spins.
- The second and third participants do not start spinning until the previous participant(s) have completed all of their spins.
- The participant who has the highest spin total not exceeding 1.00 wins $1.80. Ties are broken with a tie-breaking spinoff.
- Anyone who has a total spin score of 1.00 automatically receives a bonus of $0.20 and gets a free bonus spin. If the bonus spin comes up 1.00 then the person receives an additional bonus of $2.00. If the bonus spin instead comes up 0.05 or 0.10 then the person receives an additional bonus of $1.00.

Are there any questions now before we begin the experiment?

References

Berk, J., Hughson, E. and Vandezande, K. (1996). 'The Price is Right, but are the bids? An investigation of rational decision theory', *American Economic Review*, vol. 82, no. 5, pp. 1120–41.

Bennett, R. and Hickman, K. (1993). 'Rationality and the ''Price is Right''', *Journal of Economic Behavior and Organization*, vol. 21, no. 1, pp. 99–105.

Camerer, C. and Thaler, R. (1995). 'Anomalies: ultimatums, dictators and manners', *Journal of Economic Perspectives*, vol. 9, pp. 209–20.

Cox, J. and Oaxaca, R. (1992). 'Direct tests of the reservation wage property', ECONOMIC JOURNAL, vol. 102, pp. 1423–32.

Gertner, R. (1993). 'Game shows and economic behavior: ''risk-taking'' on ''card sharks''', *Quarterly Journal of Economics,* vol. 108, no. 2, pp. 507–21.

Healy, P. and Noussair, C. (2000). 'Bidding behavior in the ''Price is Right'' game': an experimental study', mimeo, Purdue University.

Kachelmeir, S. and Shehata, M. (1992). 'Examining risk preferences under high monetary incentives: experimental evidence from the People's Republic of China', *American Economic Review*, vol. 82, no. 5, pp. 1120–41.

Kahneman, D. and Tversky, A. (1982). 'The psychology of preferences', *Scientific American*, vol. 246, pp. 160–73.

Keren, G. and Wagenaar, W. (1985). 'On the psychology of playing blackjack: normative and descriptive considerations with implications for decision theory', *Journal of Experimental Psychology: General*, vol. 114, pp. 133–58.

Landman, J. (1987). 'Regret and elation following action and inaction: affective responses to positive versus negative outcomes', *Personality and Social Psychology Bulletin*, vol. 13, pp. 524–36.

McKelvey, R. and Palfrey, T. (1995). 'Quantal response equilibria for normal form games', *Games and Economic Behavior*, vol. 7, pp. 6–38.

McKelvey R. and Palfrey, T. (1996). 'A statistical theory of equilibrium in games', *Japanese Economic Review*, vol. 47, pp. 186–209.

McKelvey, R. and Palfrey, T. (1998). 'Quantal response equilibria for extensive form games', *Experimental Economics*, vol. 1, pp. 9–41.

Metrick, A. (1995). 'A natural experiment in ''Jeopardy!''', *American Economic Review*, vol. 58, pp. 240–53.

Radner, R. (1980). 'Collusive behavior in oligopolies with long but finite lives', *Journal of Economic Theory*, vol. 22, pp. 136–56.

Ritov, I. and Baron, J. (1995). 'Outcome knowledge, regret, and omission bias', *Organizational Behavior and Human Decision Processes*, vol. 64, pp. 119–27.

Rosenthal, R. (1989). 'A bounded-rationality approach to the study of noncooperative games', *International Journal of Game Theory*, vol. 18, pp. 273–92.

Smith, V. and Walker, J. (1993). 'Monetary rewards and decision cost in experimental economics', *Economic Inquiry*, vol. 31, no. 2, pp. 245–61.

Sonnemans, J. (1998) 'Strategies of search', *Journal of Economic Behavior and Organization*, vol. 35, pp. 309–32.

Spranca, M., Minsk, E. and Baron, J. (1991). 'Omission and commission in judgement and choice', *Journal of Experimental Social Psychology*, vol. 27, pp. 76–105.

Taylor, J. (1994). 'Betting strategies in final jeopardy', *Chance*, vol. 7, no. 2, pp. 14–27.

Tenorio, R., Bacidore, J., Battalio, R., and Milbourn, T. (1999). 'Analyzing sequential game equilibrium: a natural experiment from ''The Price is Right''', mimeo, DePaul University.

Thaler, R. (2000). 'Sudden death aversion', mimeo, University of Chicago Graduate School of Business.