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War of Attrition: Evidence from a Laboratory Experiment on Market Exit*

Ryan Oprea† Bart J. Wilson‡ Arthur Zillante§

July 5, 2010

Abstract

We report an experiment designed to study whether inefficient firms are systematically driven from overcrowded markets. Our data set includes series of 3800 wars of attrition of a type modeled in Fudenberg and Tirole (1986). We find that exit tends to be efficient and exit times conform surprisingly well to point predictions of the model. Moreover, subjects respond similarly to implementations framed in terms of losses as they do to those framed in terms of gains.

JEL Codes: D21, L11, C92

Keywords: Market exit, war of attrition, timing games, experimental economics

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1 Introduction

Young industries often undergo a process of shakeout (see for example Gort and Klepper (1982) and Klepper (1996)), attracting excess firms and gradually shedding them over time. More mature industries are likewise often forced to contract in the face of recession or product specific negative demand shocks. When an overcrowded industry is forced to shrink, which firms exit and which ones survives? One popular answer in economics is that overcrowded industries tend to shed inefficient firms and retain efficient ones. We might call this "survival of the most efficient", a process analogous to natural selection that can adaptively improve the efficiency of industries over time (see e.g. Nelson and Winter, 1982).

Fudenberg and Tirole (1986) model firms' exit decisions in overcrowded duopoly markets as wars of attrition and show that the intuition of survival of the most efficient has merit even if firms have little information regarding their costs relative to their competitors. However, the equilibrium of their game is complex, involving a solution to a system of differential equations. Since neither Fortune 500 CEOs in the naturally occurring markets nor undergraduate participants in laboratory markets deliberately solve differential equations when deciding to exit a declining market, it is an open question as to how well Fudenberg and Tirole's rational reconstruction of the exit decision corresponds to the facts of how people make such decisions.

We report the results of a laboratory experiment designed to answer this question. Nearly 200 subjects in 16 sessions participated in a total of 3800 laboratory wars of attrition based on Fudenberg and Tirole's model. At the beginning of each period, subjects were randomly paired and given a private cost draw that (usually) induced negative net per second payoffs in a shared market and positive net payoffs per second in monopoly. Subjects then decided in real time whether and when to exit the market, never to return. Monotonic equilibrium strategy functions predict higher cost (inefficient) subjects exit at an earlier time than their lower cost competitors; relatively efficient subjects survive in the market.

We find that Fudenberg and Tirole's model organizes our data surprisingly well, especially considering its complexity. We observe exit by the higher cost firm in 76 percent of cases. When differences between the costs faced by firms are substantial, the rate of efficient exit rises to nearly 100 percent. Point predictions on exit times are likewise quite close to the data, particularly in the crucial higher portion of the cost distribution that generally governs exit times. The median deviation from equilibrium exit times is zero and on average subjects earn payouts identical to those predicted in equilibrium.

Our design permits tests of two other conjectures in Fudenberg and Tirole. First our data supports Fudenberg and Tirole's core comparative static prediction that a decrease in the *ex ante* likelihood of actually being in a war of attrition leads to an increase in the speed of exit.

Second, we ran half of our sessions with costs framed as Fixed Costs (suffered while in the market) and half with costs framed as Opportunity Costs (earned by exiting the market). There is no evidence that this treatment variable affects exit behavior. This isomorphism between gains and losses, predicted by standard theory, stands in stark contrast to evidence from previous individual decision making experiments suggesting asymmetries in how subjects react to potential losses and potential gains.

Although wars of attrition have an important place in the game theoretic literature, there are surprisingly few experimental studies relating to them. Kirchkamp (2004) studies an all pay auction[1] in a near-continuous time setting like ours. He reports evidence of underbidding and marginal evidence that increased uncertainty regarding costs induces greater bids (in contrast to predictions). Bilodeau et al. (2004) study a three player full information war of attrition (framed as a volunteer game) and report widespread failure of equilibrium predictions (the predicted volunteer in a subgame perfect Nash equilibrium (SPNE) only volunteers 41% of the time). Finally Phillips and Mason (1997) consider a quantity choice game and vary whether fixed costs lead to wars of attrition at Cournot equilibrium outputs. They report evidence that subjects voluntarily enter wars of attrition in this setting.

The remainder of this paper is organized as follows. In section 2, we describe a simplified version of the Fudenberg-Tirole model. Section 3 presents our experimental design, procedures, and predictions. In section 4 we present the experimental results and conclude in section 5.

[1] Bulow and Klemperer (1999) show that all pay auctions are isomorphic to wars of attrition.

2 Model

Consider the following stripped down version of Fudenberg and Tirole (1986).[2] Firms $i = 1, 2$ compete in a market in continuous time, earning duopoly revenues R^D while they do. If one firm exits the market, the remaining firm earns monopoly revenues $R^M > R^D$ forever. Firm i incurs a fixed cost c_i drawn independently and privately from a common (and common knowledge) uniform distribution $U[\underline{c}, \overline{c}]$ as long as it is in the market. Without loss of generality assume $c_1 < c_2$. Firm i's profits at each instant are:

$$\pi_i = \begin{cases} R^D - c_i & \text{if both are in the market} \\ R^M - c_i & \text{if only } i \text{ is in the market} \\ 0 & \text{if } i \text{ is not in the market} \end{cases} \tag{1}$$

Time is discounted at a rate $r \in (0, 1)$. The agent's strategy is a time t_i at which to exit the market if her counterpart has not yet left.

When $c_1 > R^D$, agents are in a war of attrition; both suffer losses as long as they share the market yet each would prefer the other leave first. If war of attrition is guaranteed *ex ante* (if $\underline{c} > R^D$) such a game notoriously has a continuum of perfect Bayes equilibria (see for example Riley (1980) and Nalebuff and Riley (1985)). However, by introducing a small probability that $c_1 < R_D$ (accomplished by setting $\underline{c} < R^D$), the set of symmetric equilibria shrinks to one. The unique equilibrium strategy function takes the form of a monotonically decreasing time $T_i(c_i)$ at which agent i leaves the market if (and only if) her counterpart has not yet exited. This monotonicity gurantees survival of the most efficient; the highest cost firm is the one driven from the market.

The intuition for this result is relatively straightforward. A firm plans to exit at the moment when the cost of staying in the market for another moment just equals the expected benefit. The instantaneous cost of remaining in the market is $R^D - C_i(t)$ (where $C_i(t) \equiv T_i^{-1}(t)$) while the benefit is that the competitor may leave yielding discounted returns of $\frac{R^M - C_i(t)}{r}$. The probability a competitor actually leaves in the coming instant, conditional on not having left already, is given by the probability that the firm faces a cost that would not

[2] Fudenberg and Tirole provide analogous results for firms facing a more general class of cost distributions and time varying revenues.

induce it to exit now but would induce it to exit in an instant. This in turn is given by the product of the hazard rate at the cost that would induce present exit, $\frac{1}{C_i(t)-\underline{c}}$, and the slope of the exit cost function, $C'_{-i}(t)$. Setting cost equal to expected benefits, imposing symmetry and rearranging, we arrive at the following differential equation:

$$C'_i(t) = r\left[C_i(t) - \underline{c}\right]\left[\frac{C_i(t) - R^D}{C_i(t) - R^M}\right]. \tag{2}$$

Finally, a firm with a cost as high as the monopoly revenue should immediately exit the market. Firm i's strategy function, $T_i(c)$ is therefore the inverse of the solution to (2), subject to the boundary condition $C_i(0) = R^M$.[3] This function is strictly monotonic on $[R_D, R_M]$, infinite below this range and zero above.

A core comparative static prediction of Fudenberg and Tirole (1986) is that increasing the mass of the distribution towards $\underline{c}$ leads to (weakly) earlier exit times for each cost type. This is because doing so increases the probability that one's competitor will never leave. The uniform distribution has constant mass, ruling out an exact test of this prediction. An analogous prediction, available under a uniform distribution, is that a distribution with a lower value of $\underline{c}$ will induce earlier exit for each cost draw. Numerical results, provided in Section 3.1, indicate that this is indeed true for our parameters and we use this fact to test the spirit of this prediction from Fudenberg and Tirole (1986).

We have so far framed costs as fixed losses suffered by remaining in the market. As Fudenberg and Tirole (1986) note, the model can alternatively be described in terms of opportunity costs foregone by remaining in the market. To be precise, changing the profit function to

$$\pi_i = \begin{cases} R^D & \text{if both are in the market} \\ R^M & \text{if only } i \text{ is in the market} \\ c_i & \text{if } i \text{ is not in the market} \end{cases} \tag{3}$$

yields identical equilibrium strategy functions.

[3] Another available boundary condition is that firms with costs equal to duopoly profits should never exit meaning $\lim_{t\to\infty} C_i(t) = R^D$.

3 Design, Procedures and Predictions

We ran a total of 16 sessions each with 12 subjects (except for one session with 10 subjects) and 20 periods of play. In each period we randomly matched subjects into pairs to play discrete, real time implementations of Fudenberg and Tirole's model.

Subjects begin each period in duopoly and each can unilaterally exit at any time prior to the period's random expiration time. In all sessions, subjects earn revenues $R_D = 100$ for each second they spend sharing the market and $R_M = 100$ for each second spent in the market alone. Because infinite periods are impractical, we induce impatience by instituting a 1 percent per-second hazard that the current second would be the period's last (equivalent to setting a discount rate $r = 0.01$).

At the beginning of each period subjects are assigned an independent cost drawn from a symmetric, common knowledge distribution. In 8 sessions costs are drawn from the Narrow cost distribution ($c_i \in [95, 405]$) and in 8 further sessions they are drawn from the Wide cost distribution ($c_i \in [40, 460]$).[4] This between session variation constitutes our main treatment variable, allowing us to test Prediction 3, below.

As Fudenberg and Tirole note, the model's predictions do not depend on whether firms face opportunity costs from being in the market suffer realized fixed cost from being in it. To enable tests of this prediction (Prediction 4, below), half of our sessions use a Fixed Cost implementation and half use an Opportunity cost implementation. In 8 Opportunity cost sessions (4 under each cost distribution) subjects earn R_D when sharing the market, R_M when in the market alone and c_i when out of the market. In 8 Fixed Cost sessions (again 4 under each cost distribution), subjects are assigned 25,000 in initial capital. [5] They then

[4]These cost distributions (a) satisfy the necessary condition for uniqueness of equilibrium in FT given our parameters of $R^M = 400$ and $R^D = 100$ and furthermore (b) allow some separation between the predicted equilibrium exit times for subjects who draw the same cost under different cost treatments. The mean of each is the mean of the duopoly and monopoly revenues meaning equilibrium subjects were equally likely to exit instantly and to never exit at all.

[5]The starting capital is calibrated to cover equilibrium duopoly losses given randomly determined period lengths. This calibration worked well; in only 3 cases did a subject exhaust this capital and only prior to period 10. In these cases subjects were forced out of the market as it is infeasible to allow subjects to earn negative cash amounts.

earn $R_D - c_i$ for each second they spend as duopolists, $R_M - c_i$ for each second as monopolists and 0 for each second spent outside the market. We pose the predicted isomorphism between these sessions as Prediction 4 below.

Half of our sessions were conducted at George Mason University in October 2005 and half at Chapman University in April 2009 and these locations were balanced across the treatment design. Twelve subjects participated in each session but one (which contained 10 subjects). Subjects were paid based on one randomly selected period and received \$1 for each 3000 points earned. Subject payments, including a \$5 payment for showing up (\$7 in Chapman sessions), ranged from \$7.75 to \$33.75, and averaged approximately \$15 for sessions lasting up to 75 minutes.

3.1 The Model's Predictions and Alternatives

The model makes four main testable predictions under our experimental design. We outline and motivate them below and conclude the section with a discussion of their plausibility and reasonable alternative predictions.

Most of the predictions of the model can be visualized in Figure 1 which plots numerical strategy functions derived from (2). A first and main prediction follows directly from the monotonicity of these strategy functions; a higher cost firm must exit before the lower cost firm, generating an efficient pattern of exit and "survival of the most efficient".

Prediction 1. *Higher cost firms tend to exit the market and lower cost firms tend to remain.*

A far more stringent prediction is that subjects employ strategy functions quantitatively similar to equilibrium ones. Testing the point predictions is complicated by two forms of censoring in our data, unavoidable in our design. First, period lengths are random and sometimes end prior to either subject making an exit decision. Second, we can only observe one exit decision per pair.

The theory provides guidance on how to form testable predictions in the face of these complications. First, the model provides predictions only for periods that last long enough to permit equilibrium behavior. Therefore our predictions are necessarily specialized to periods that last long enough to admit equilibrium exit times. Second, the theory makes predictions

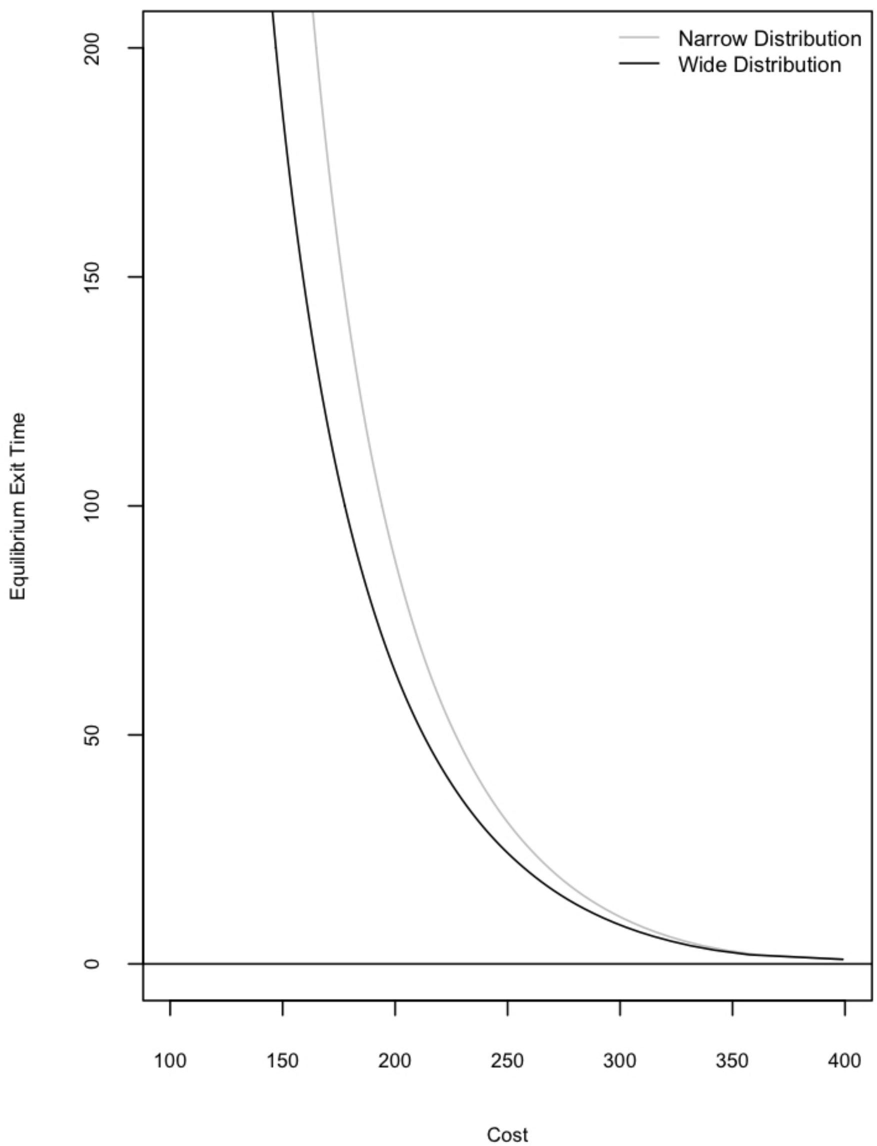

Figure 1: Equilibrium strategy functions.

about the exit times experienced by pairs of subjects. Specifically, the timing of exit events should follow the equilibrium strategy function of the *higher cost firm*.[6] Together these generate a quantitative prediction, testable using our data.

Prediction 2. *In periods long enough to admit equilibrium behavior, the observed exit time will be close to the higher cost firm's equilibrium strategy, plotted in Figure 1.*

The strategy functions plotted in Figure 1 are distinct because the two cost distributions have different mass below the duopoly revenue level. The differences between these strategy functions predict a treatment effect across sessions under our design:

Prediction 3. *Wars of attrition resolve more quickly in Wide distribution sessions than in Narrow distribution sessions.*

Finally, Fudenberg and Tirole point out and standard economic theory predicts that the direct losses incurred in Fixed Cost sessions and the earnings foregone out-of-market in Opportunity Cost sessions will induce similar behavior.

Prediction 4. *Exit behavior is similar in Opportunity Cost and Fixed Cost sessions.*

The model's predictions are computationally demanding, requiring agents to solve a system of differential equations and to properly impute similar reasoning to their opponents. The literature is littered with examples of models (e.g. the theory of competitive equilibrium) that organize complex human decision making quite well though not because human subjects are adroit theorists. Clearly neither subjects nor business executives employ involved mathematics when making timing decisions, and this is not the question posed by our experiment (we're pretty confident our subjects were not solving differential equations in their heads during our sessions). Rather our aim is to learn whether Fudenberg and Tirole's model is a good description of heuristic human decision making.

Of course the literature is also littered with examples of models failing to predict human behavior (e.g. centipede games). Interestingly, such a failure need not spell disaster for the model's central prediction that efficient firms survive in markets (Prediction 1). Even if the point predictions (Prediction 2) of the model fail spectacularly, efficient exit will prevail as

[6] Jointly, these two restrictions mean that we will have access to data on the strategy function for, roughly, the upper 2/3 of the cost function. As it turns out this is the most important part of the strategy function as it is the part most likely to govern the timing of the exit event.

long as strategy functions are monotonically decreasing. Other plausible heuristics will lead to inefficient exit and a rejection of Prediction 1. For instance subjects may choose to exit without much regard to variations in costs, hoping only to outlast their opponents. The resulting flat strategy functions will fail to systematically weed out inefficient subjects.

Prediction 4 rests on a fundamental isomorphism in economic theory between explicit losses and foregone opportunities. There is some experimental evidence showing that subjects sometimes treat the two types of payoff possibilities quite differently and these observations have been formalized as the theory of loss aversion (e.g. Kahneman and Tverksy 1979, 1991). Loss aversion would seem to predict earlier exit times under Fixed Cost sessions (where losses are explicitly suffered while in the market) than under Opportunity Cost sessions (where gains are simply smaller than those available outside of the market). We consider this a reasonable alternative hypothesis to Prediction 4 and the experiment was designed to enable a sharp test.

4 Results

As we point out in the previous section, the model only makes predictions for periods that last long enough to admit equilibrium behavior. We therefore restrict attention to period/pair combinations for which equilibrium strategies are, in principle, observable.[7] Further, to focus on the decisions of relatively experienced subjects we focus our analysis on data from the final half (final 10 periods) of each session.

The model's first prediction is that the higher cost firm in any pair tends to exit the market and the lower cost firm tends to remain. In our data higher cost firms exit the market 76 percent of the time while lower cost firms exit in only 18 percent of pairs. The remaining 6 percent of cases are censored by expiration.

In order to formally test the prediction, we examine, for each session, the difference in rates of exit by higher and lower cost firms. Using the difference in session level rates (high

[7]Expiration times are exogenous, unknowable to subjects and uncorrelated with observables such as cost. This method of sampling therefore does not introduce any new source of bias and has been used in previous work (see e.g. Oprea et al. (2009)).

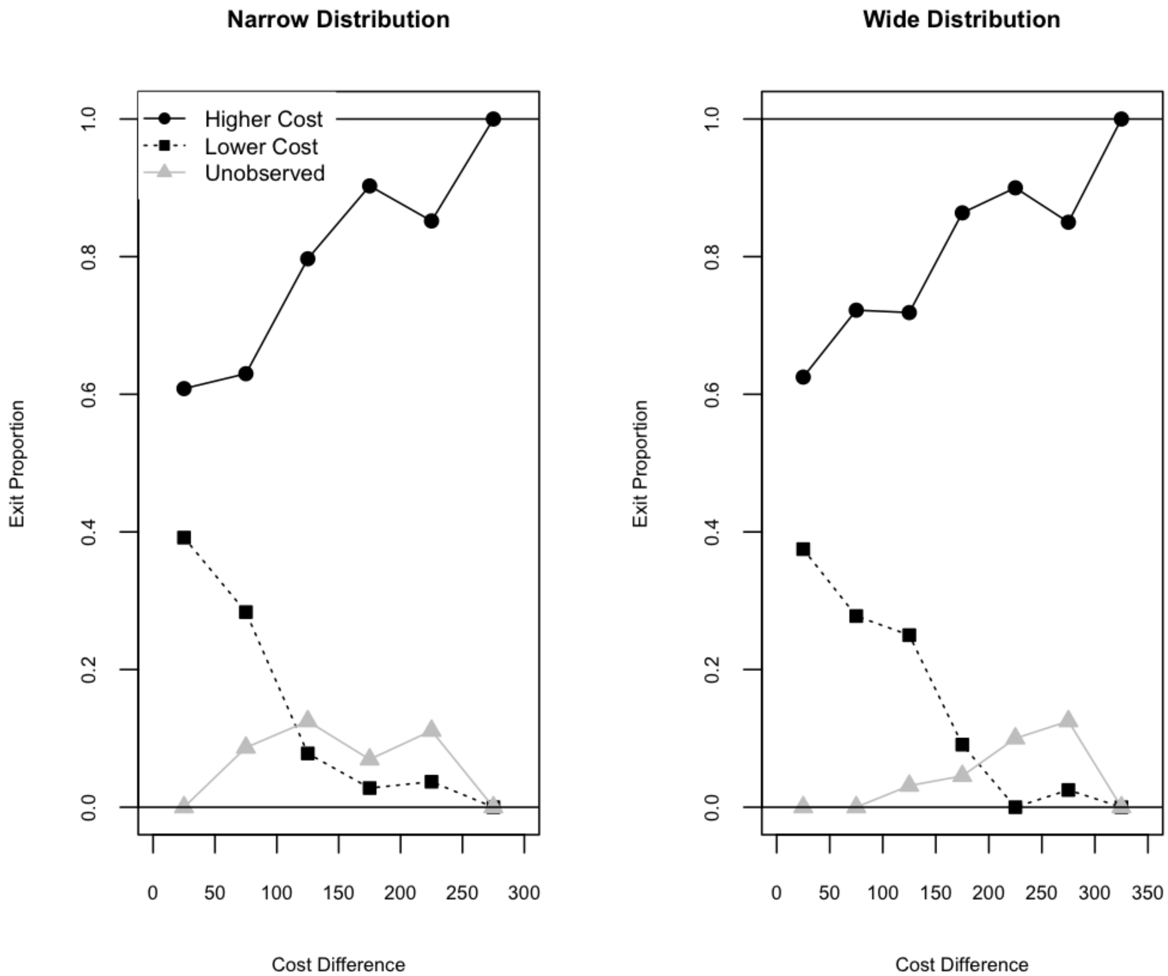

Figure 2: Propensity of efficient and inefficient firms to exit as a function of the difference between their costs.

cost rate of exit minus low cost rate of exit) as our unit of observation, we conduct Wilcoxon signed rank tests for Narrow and Wide cost distributions (giving us 8 data points for each test). This statistic is significantly greater than zero under both Narrow (p=0.01415) and Wide (p=0.008) cost ranges.[8]

Very inefficient firms are far more likely to exit first than only slightly inefficient firms. Figure 2 plots rates of exit for higher cost and lower cost firms as a function of the cost difference between the two firms in a pair. Under both Narrow and Wide cost ranges, we observe a strong increasing (decreasing) relationship between the difference in costs and the rate of exit by higher (lower) cost firms. Thus, inefficient firms are more likely to exit the more inefficient they are relative to their competitors. Efficient exit is substantially more likely the more it enhances efficiency.[9]

Result 1. *The higher cost firm in a pair tends to exit and the lower cost firm tends to remain. Greater cost differences induce higher rates of efficient exit.*

The model's second prediction is that subjects exit at times consistent with the equilibrium strategy function. As we pointed out above, our data here is doubly censored. First, in roughly six percent of cases the period ends before an exit decision is made. Second, we only observe one exit time per pair. Were we to look only at observed exit times as a function of cost, we would necessarily face a severely downward biased sample.

We can reduce or eliminate this bias by focusing on the behavior of the pair's higher cost subject,[10] whose decisions in both theory and fact are generally uncensored. When we do not observe the higher cost firm's exit decision due to censoring either by the lower cost firm or expiration, we are provided a lower bound on the higher cost firm's exit time. The combination of observed exit behavior and censoring times gives us a lower bound estimate on the higher cost firm's strategy function. Since expiration censoring is rare and lower cost

[8]We pool Fixed and Opportunity Cost sessions to fully take advantage of our factorial design and to permit higher power tests. As we show below (and as predicted) there are no significant differences between Fixed and Opportunity Cost sessions.

[9]This is precisely the pattern expected with any noisy implementation of the strategy function.

[10]Note that subjects do not know whether they are the higher cost subject in any given period and in general a subject will be the high cost and the low cost subject multiple times in the experiment. Thus estimates of the higher cost subject's strategy function also functions as an estimate of the latent strategy utilized by lower cost subjects.

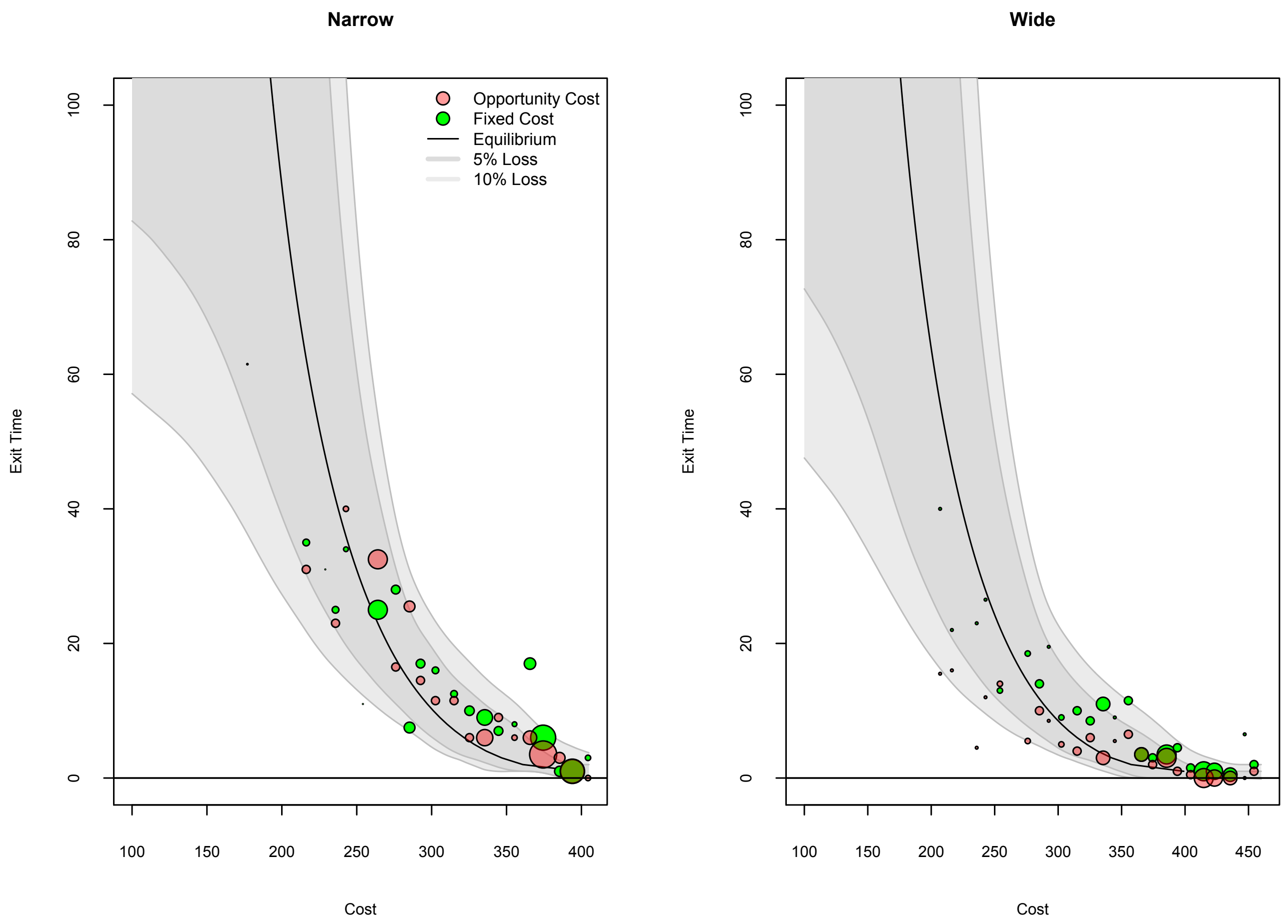

Figure 3: Timing of exit. Points are medians from 10 point bins binned and scaled based on the number of observations. Plots also show regions resulting in a 5% or smaller (dark gray) and 10 % or smaller expected loss relative to best response.

exit tends to occur when costs are similar, this lower bound is likely to be close to the true strategy function.

Exit times are centered precisely on predictions; under each cost distribution, the median deviation of observed exit times from equilibrium predictions is 0. In order to provide a conservative test of deviations from predicted exit times, we examine the 16 by-session median deviations of resolution times from predicted times. The median of by-session median deviations is only one half of a second, a number indistinguishable from zero at the five percent level (Wilcoxon test, $p = 0.071$).

Figure 3 plots median exit time estimates for each pair as a function of the pair's high cost. Costs are binned in 10 point intervals and points are scaled to the number of observations in the bin to give a visual sense of empirical weight. Data from Fixed Cost sessions are plotted in green and those from Opportunity Cost sessions in red. In both Narrow and Wide distributions, points track the equilibrium quite closely, especially at higher costs and especially where there is the most data (larger points).

Figure 3 also displays gray bands representing the equilibrium payoff function away from the best response. Dark gray areas represent points expected to lead to a less than 5 percent loss relative to equilibrium play and light gray areas a less than 10 percent loss. Most of the medians lie in the 5 percent bounds and virtually all lie in the 10 percent bounds. Thus even estimates that deviate from the strategy function in Figure 3 are generally very nearly equilibrium best responses.

Result 2. *Exit timing tracks the equilibrium strategy function quite closely in all treatments. The median deviation from equilibrium times is zero.*

On average subjects play near-best responses to equilibrium strategies. How much do subjects on average actually forego by playing observed strategies rather than precise equilibrium strategies? To find out we look, for each subject, at the difference between observed earnings and counterfactual earnings from joint equilibrium play. We plot CDFs for each treatment in Figure 4. The median foregone earnings from deviations from equilibrium are zero and in each case are roughly symmetrically distributed. A Wilcoxon test using by-session medians as units of observation cannot distinguish the difference from zero at the five percent level ($p = 0.077$).

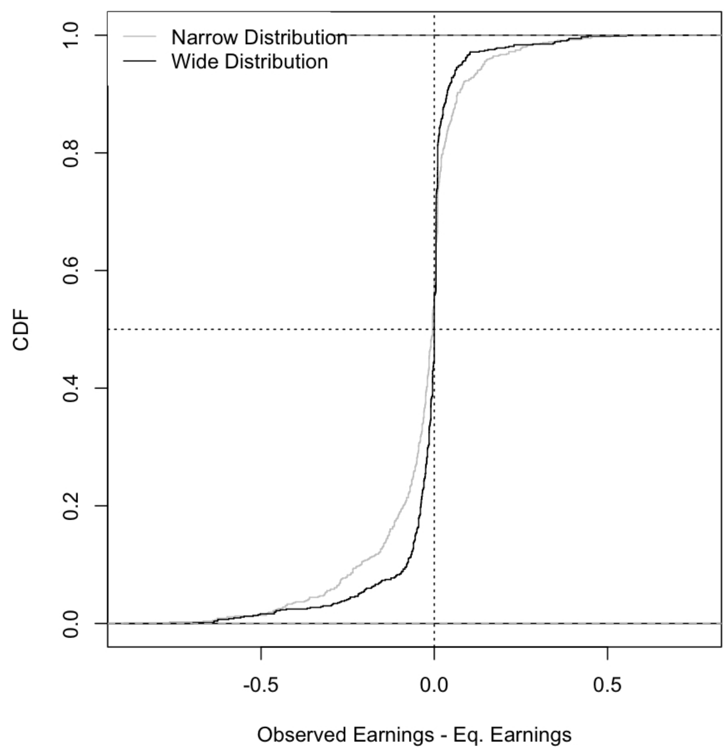

Figure 4: CDFs of the difference between observed payoffs and equilibrium payoffs.

Result 3. *Observed earnings are insignificantly different from equilibrium earnings.*

We now turn to treatment level tests of the model's comparative static predictions. The model's first comparative static prediction (Prediction 3) is that Narrow cost distributions induce later exit than Wide cost distributions. In order to test this prediction we compare by-session median exit times across cost distributions. Mann-Whitney tests allow us to reject the hypothesis that the two are equal at the one percent percent level ($p < 0.001$).

Result 4. *As predicted, wars of attrition are lengthier when the support of the cost distribution is less diffuse.*

The final prediction of the theory (Prediction 4) is that behavior in Opportunity Cost sessions is no different from behavior in Fixed Cost sessions. Figure 3 provides some evidence. Purple points are generally quite close to green dots in both cases indicating little difference between cost types. Under the Wide distribution, Fixed Cost exit times actually appear to be a bit *later* than Opportunity Cost times, the opposite of the effect suggested by loss aversion.

We conduct two statistical tests of Prediction 4. First we consider whether the efficiency of exit is impacted by the type of cost experienced. We examine the difference in rates of exit by higher cost and lower cost firms for each session. Comparing session medians of these differences across Fixed and Opportunity Cost implementations with a Wilcoxon test, we cannot reject the hypothesis that the net rate of efficient exit is identical ($p = 0.172$). Next we consider whether the timing of exit events is affected by the type of cost. We compare by-session median exit times across Opportunity and Fixed Cost implementations using a Mann-Whitney test and fail to reject the hypothesis that subjects exit at the same times ($p = 0.429$). Thus:

Result 5. *Exit behavior is not significantly affected by the type of cost.*

5 Discussion

We examined 3800 laboratory exit timing games conducted with nearly 200 subjects over 16 experimental sessions. In most duopoly pairs, the subject assigned the higher cost exited prior to their lower cost competitor. Our results therefore support Fudenberg and Tirole's (1986) prediction that efficient firms tend to survive in markets.

Finer points of Fudenberg and Tirole's computationally intensive model are surprisingly well supported by the data. The median deviation of exit times from equilibrium predictions is zero and over a large cost range exit times match the strategy function quite well. Moreover, earnings of the median pair are equal to their counterfactual equilibrium earnings.

The data also support two ancillary predictions. First, as the Fudenberg-Tirole model predicts firms engage in shorter wars of attrition when there is a greater probability that one's rival has no incentive to exit. Second, firms react to the potential for gain outside of the market in a way that is nearly symmetric to the way they react to losses suffered while in the market. That is, subjects' behavior is not affected significantly by changing fixed costs suffered in the market into opportunity costs captured by leaving the market. This result stands in contrast to asymmetric behavior to gains and losses observed in a number of individual decision making environments. Along with Rappaport, Seale, Erev, and Sundali (1998), our results suggest that these types of asymmetries may be less prevalent or have a lesser impact in strategic settings.

Besides providing direct facts on an important market mechanism, our experiment highlights the powerful predictive potential of economic theory. Economics experiments often emphasize deviations from models, usefully illuminating the failure of economic theory to account for important features of individual decision making. No less illuminating is the large body of evidence to which we contribute showing that even mathematically involved models often beautifully anticipate the outcomes of human interactions.

Our experiment is conducted in real time, allowing subjects to experience a relatively realistic simulation of the problem being studied. While we believe this is the appropriate way to study models with time dimensions, it does not come without costs. Censoring, unavoidable in a real-time implementation, allows us a credible estimate of only the upper 2/3 of the strategy function. Future research might revisit our research using the strategy method, perhaps yielding additional insight on the empirical strategy function.

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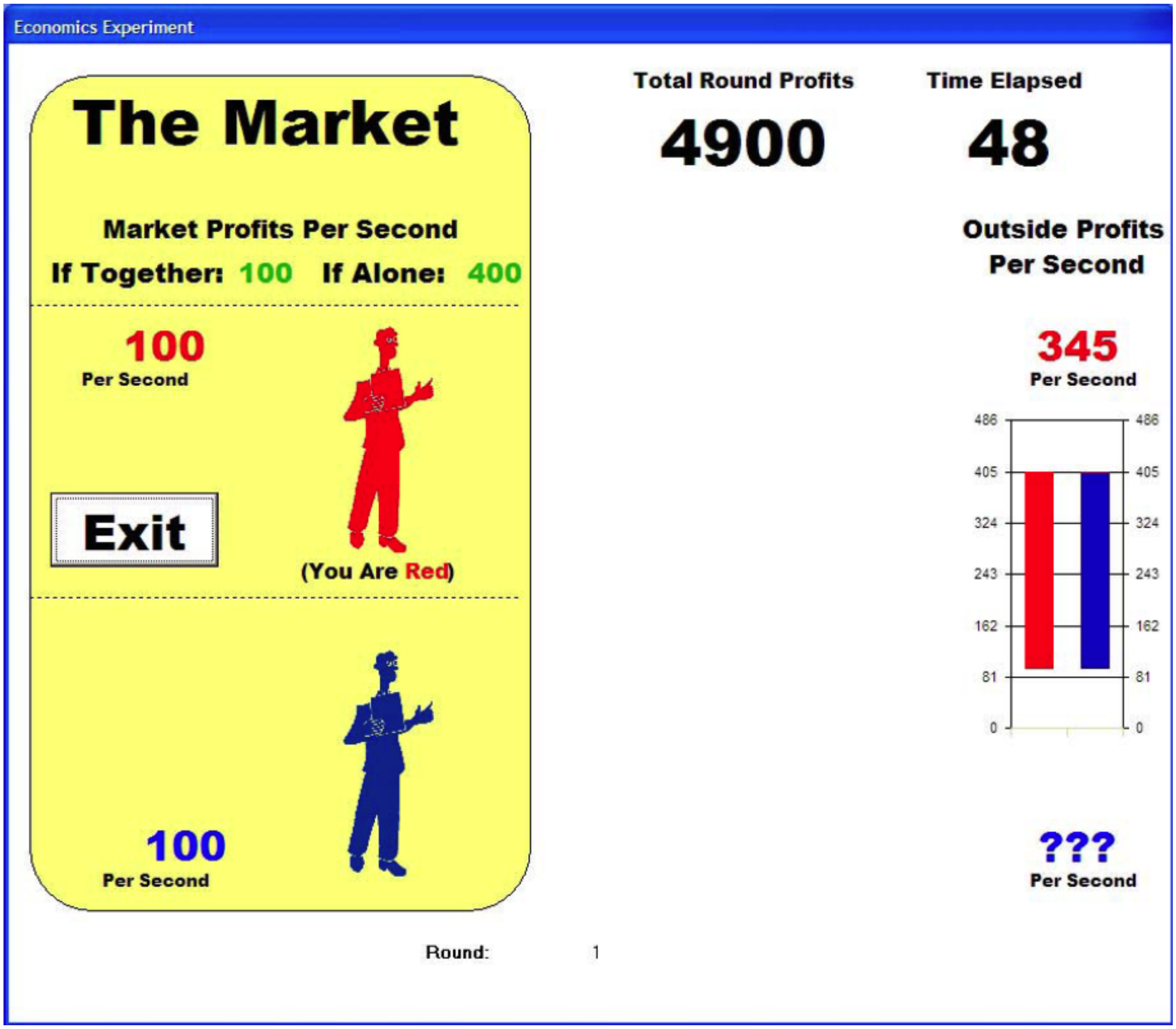

Figure 5: Opportunity Cost treatment screenshots.

Appendix: Instructions for the Experiment

Instructions for the OCH Sessions

Thank you for participating in today's experiment in economic decision-making. If you have any questions please do not hesitate to ask myself or one of the other experimenters. At this time I ask that you refrain from talking to any of the other participants.

This experiment will last for 20 rounds. In this experiment, you will earn ECUs. At the end of the experiment, you will earn $1 for each 3000 in ECUs you earn. Your total round

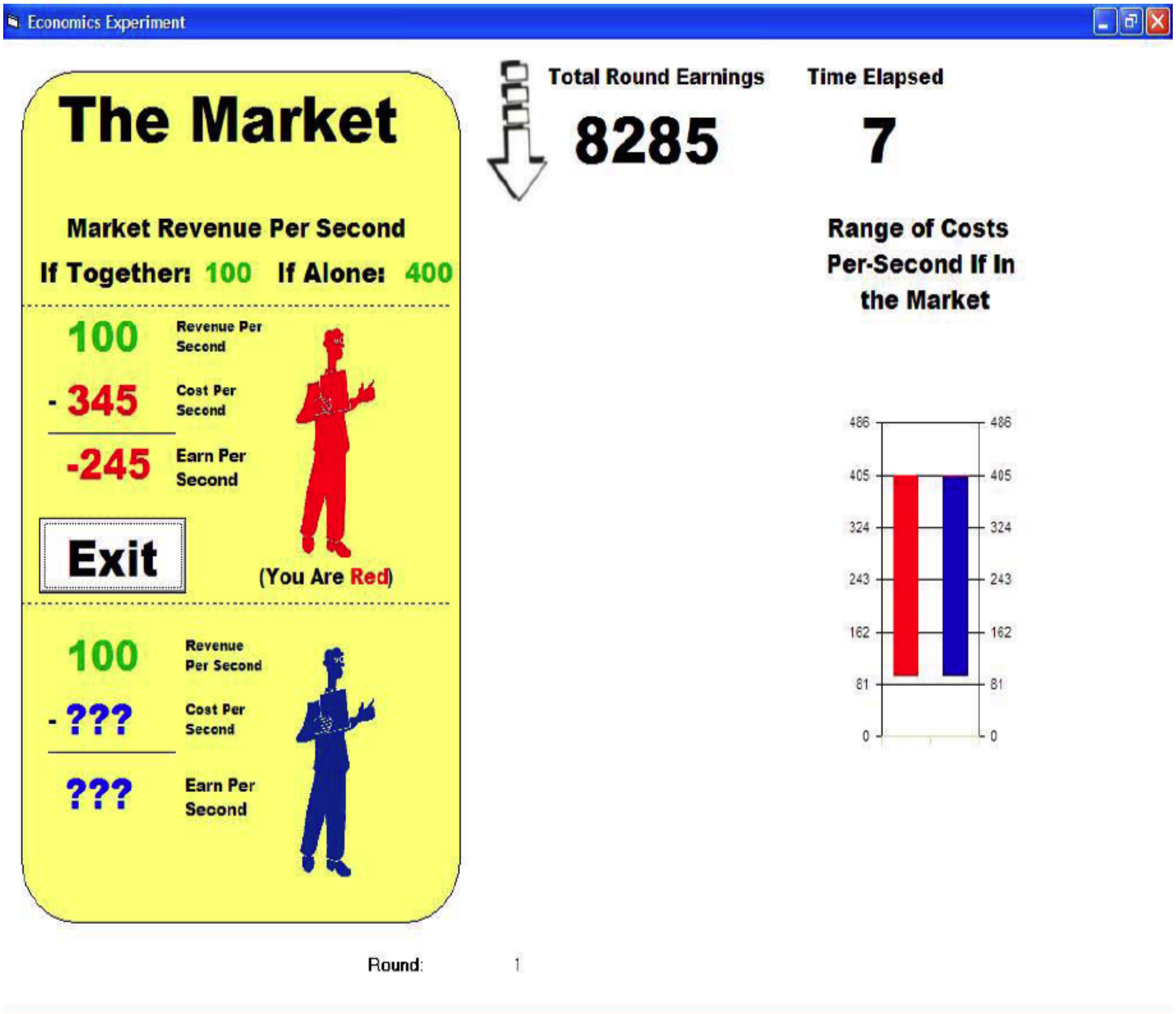

Figure 6: Fixed Cost treatment screenshots.

profits are listed on the top of your screen. At the end of the experiment, one participant will pick a number out of a hat and you will be paid your earnings for the round that corresponds to the chosen number. These earnings are in addition to your $5 show-up fee.

In this experiment, you will be either a Red or Blue participant for the entire experiment. If you are a Red participant it will read, "You are red" under the red figure on your screen, and if you are a Blue participant it will read, "You are blue" under the blue figure. You will be randomly matched with another participant in the room for each of the 20 rounds of the experiment. The current round that the experiment is in is displayed on the bottom of the screen.

Each round will last for a number of seconds. At each second, there is a 1 percent chance that the round will randomly end.

At the beginning of each round, both you and your counterpart are in the Market. The Market is the yellow area on your screen. As each second passes you will remain in the Market unless you choose to exit. You can choose to exit the Market by pressing the exit button next to your figure. When you exit, your figure will literally walk out of the Market.

If you choose to exit the Market you will remain out of the Market for the remainder of the round.

How do I earn money?

You will earn money each second during a round. Your earnings per second will be based on whether you are in the Market and whether your counterpart is in the Market.

When both you and your counterpart are in the Market, you each earn 100 ECUs per second. However, if one of you chooses to exit the Market, then the one who is left alone in the Market will earn 400 ECUs per second.

Do I earn money if I exit the Market?

Yes, you earn money if you exit the Market. On the right-hand side of the screen is a chart labeled Outside Profits Per Second. The red bar on the chart shows the range of possible amounts Red could earn per second when he is outside of the Market. The blue bar on the chart shows the range of possible amounts Blue could earn per second when he is outside of the Market. Notice that they are the same, and range between 40 and 460.

At the beginning of each round, you will receive a randomly drawn number out of this range. You will be shown this number, so you will know exactly how much you will earn if you leave the Market.

Your counterpart will also receive a randomly drawn separate number out of this range. He will see this number and know exactly how much he will earn if he leaves the Market, but you won't. You will only know the range.

(Note: You will only receive whole numbers from the range of 40 to 460, not fractions. The random procedure used makes it equally likely that each of these values is chosen).

If you choose to exit the Market, then your figure will physically move into the middle of the screen, and your outside profits value will also move to the middle of the screen, signaling that you are now earning the outside profits value. If the other participant exits the Market, then you will see that participant's figure move to the middle of the screen, and his or her outside profits value (which you still won't know) will also move to the middle of the screen.

Note that if the other participant exits the Market, you will earn the "If alone" profit of 400 per second. If you exit the Market, then the other participant will earn the "If alone" profit of 400 per second.

Please recall that if you exit the Market you cannot reenter the Market for the remainder of the round.

Must someone exit the Market?

Each participant can choose how long he or she stays in the Market – no one will be forced to exit the Market. Also, no participant will be forced to stay in the Market – it is possible that both participants choose to exit the Market. There will be 20 rounds of the experiment. There will be 10 seconds between each round, at which time you will be randomly paired with a NEW participant and each of you will randomly receive a NEW Outside Profits Per Second value.

A few reminders before we begin:

1. You will be either a Red or Blue person for the entire experiment.

2. Each round you will be randomly matched with a new participant.

3. Each round you will receive a new outside profits value draw.

4. There is a 1 percent chance each second that the round will end.

5. Once you have decided to exit the Market for a round you will remain out of the Market for the remainder of the round.

6. One round will be randomly chosen at the end of the experiment and your earnings will be based on your total round profits from the round that is randomly chosen. Recall that 3000 ECUs = $1.

If there are no more questions we will begin momentarily. Please feel free to ask questions throughout the duration of the experiment.

Instructions for the FCH sessions

Thank you for participating in today's experiment in economic decision-making. If you have any questions please do not hesitate to ask myself or one of the other experimenters. At this time I ask that you refrain from talking to any of the other participants.

This experiment will last for 20 rounds. In this experiment, you will earn ECUs. At the end of the experiment, you will earn $1 for each 3000 in ECUs you earn. Your Total Round Earnings, updated each second, are listed on the top of your screen. At the end of the experiment, one participant will pick a number out of a hat and you will be paid your earnings for the round that corresponds to the chosen number. These earnings are in addition to your $5 show-up fee.

In this experiment, you will be either a Red or Blue participant for the entire experiment. If you are a Red participant it will read, "You are red" under the red figure on your screen, and if you are a Blue participant it will read, "You are blue" under the blue figure. You will be randomly matched with another participant in the room for each of the 20 rounds of the experiment. The current round that the experiment is in is displayed on the bottom of the screen.

Each round will last for a number of seconds. At each second, there is a 1 percent chance that the round will randomly end.

At the beginning of each round, both you and your counterpart are in the Market. The Market is the yellow area on your screen. As each second passes you will remain in the Market unless you choose to exit. You can choose to exit the Market by pressing the exit button next to your figure. When you exit, your figure will literally walk out of the Market.

If you choose to exit the Market you will remain out of the Market for the remainder of the round.

How do I earn money?

Each participant will begin each round with 25,000 ECU's in Total Round Earnings. During each second, your Total Round Earnings will either increase or decrease. The change in your earnings each second will be based on whether you are in the Market and whether your counterpart is in the Market.

There are two factors that affect how your earnings change when you are in the Market: Your revenue and your cost.

When both you and your counterpart are in the Market, you each receive a revenue of 100 ECUs per second. However, if one of you chooses to exit the Market, then the one who is left alone in the Market will receive a revenue of 400 ECUs per second.

You and your counterpart will also each incur a cost of being in the market for each second you are in the market. On the right-hand side of the screen is a chart labeled "Cost per second when in the market." The red bar on the chart shows the range of possible costs Red could have to pay per second when he is in the Market. The blue bar on the chart shows the range of possible costs Blue could have to pay per second when he is in the Market. Notice that they are the same, and range between 40 and 460.

At the beginning of each round, you will receive a randomly drawn number out of this range. You will be shown this number, so you will know exactly what your cost is for each second you are in the Market. This cost is shown on the left-hand side of your screen. Does everyone see where their cost is?

Your counterpart will also receive a randomly drawn separate number out of this range. He will see this number and know exactly what his cost is for each second he is in the Market, but you won't. You will only know the range.

(Note: You will only receive whole numbers from the range of 40 to 460, not fractions. The random procedure used makes it equally likely that each of these values is chosen).

Each second, the change to your Earnings is determined by subtracting your cost from your revenue. If your cost is higher than your revenue, then you will earn NEGATIVE profits and lose earnings each second. If your revenue is higher than your cost then you will earn POSITIVE profits and you will gain earnings each second.

There are two ways to tell whether you are gaining or losing money each second. First, while you are in the market you will be able to see whether your "Earn Per Second," shown in the yellow part of the screen, is negative. If it is negative, then you are losing money. If it is positive then you are earning money. Second, next to your "Total Earnings Per Second" will be an arrow. If the arrow is pointing down, you are losing money; if the arrow is pointing up, you are earning money.

Note that it is possible for a participant to begin a round incurring losses (negative profits), but then switch to earning money (positive profits) if the other participant exits the market.

If you choose to exit the Market, then your figure will physically move into the middle of the screen. If the other participant exits the Market, then you will see that participant's figure move to the middle of the screen.

Note that if the other participant exits the Market, you will receive the "If alone" revenue of 400 per second. If you exit the Market, then the other participant will receive the "If alone" revenue of 400 per second. Please recall that if you exit the Market you cannot reenter the Market for the remainder of the round.

What happens to my revenue per second, cost per second, and total round profit if I exit the Market?

If you choose to exit the Market then your revenue per second and cost per second both become zero and your Total Round Earnings stop changing. Whatever your Total Round

Earnings are when you exit the market will be your final Total Round Earnings for that round.

Must someone exit the Market?

Each participant can choose how long he or she stays in the Market., with one exception. If your Total Round Earnings ever reach zero (i.e. if you ever run out of money), you will be forced to exit the market. A message reading "You ran out of money" will appear on your screen, and your figure will exit the market No participant will be forced to stay in the Market – it is possible that both participants choose to exit the Market.

There will be 20 rounds of the experiment. There will be 5 seconds between each round, at which time you will be randomly paired with a NEW participant and each of you will randomly receive a NEW Cost Per Second value.

A few reminders before we begin:

1. You will be either a Red or Blue person for the entire experiment.

2. Each round you will be randomly matched with a new participant.

3. Each round you will receive a new starting amount of 25,000 ECUs.

4. Each round you will receive a new cost per second.

5. There is a 1 percent chance each second that the round will end.

6. If your Total Round Earnings ever run out (reach zero), then you will be forced out of the market.

7. Once you have decided to exit the Market for a round you will remain out of the Market for the remainder of the round.

8. One round will be randomly chosen at the end of the experiment and your earnings will be based on your total round profits from the round that is randomly chosen. Recall that 3000 ECUs = $1.

If there are no more questions we will begin momentarily. Please feel free to ask questions throughout the duration of the experiment.

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08-01 Oprea, R., Porter, D., Hibbert, C., Hanson, R. and Tila, D. Can Manipulators Mislead Prediction Market Observers?