Selection Pressure in Repeated Contests

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Competition for scarce resources in the face of birth and death (the struggle for survival) has shaped social and economic interaction since the beginnings of mankind. This research is the first to induce selection pressure in controlled strategic decision-making experiments using performance-based replacement of participants over time. Strategic decision-making with and without selection pressure is considered in repeated Tullock-type rent seeking contests. Tullock contests' incentive structure drives a wedge between profit maximization and survival. Moreover, there is a large number of past experiments without selection pressure demonstrating a willingness to compete that cannot be justified by profit maximization alone and thus seemingly supports evolutionary game-theoretic predictions. Surprisingly, we find that the intensity of competition in repeated contests does in fact *decrease* once selection pressure is added. Participants' behavior under selection pressure is well-approximated by the finite population evolutionarily stable strategy (ESS) of the stage game. This happens because a significant share of contestants quickly adapt to survive under selection pressure at the expense of new entrants. By contrast, when selection pressure is absent, we observe a large variance in competitiveness and frequent competition far beyond profit-maximizing levels. Selection pressure has a disciplining effect on contestants' decision-making, boosting not only the lifespans of successful contestants but also average round payoffs across the entire population.

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1 Introduction

Much of human history has been governed by the "perpetual struggle for room and food" (Malthus, 1798, p. 84), i.e., the competition between individuals and groups for scarce resources in the face of birth and death. In economics, Alchian (1950) first pointed out that competition between firms and other agents in modern society involves similar selection pressures. In particular, just like the struggle for "biological survival", the struggle for "economic survival" features repeated contests in which "losers" (e.g., bankrupted firms) are replaced by "newly birthed" contestants (e.g., entrants) whereas "winners" (e.g., incumbent firms) live to see another day.

In this paper, we investigate how real-life humans adapt their behavior to the presence of evolutionary selection pressures in an incentivized decision-making experiment. Specifically, we consider repeated Tullock contests, which are known to feature a conflict between profit maximization- and survival-incentives (Schaffer 1989, Hehenkamp et al. 2004, Alós-Ferrer and Ania 2005).

Our experiment has subjects play repeated contests where, as in previous experiments, they earn money based on their decisions. Differently from previous experiments, there is stochastic "birth and death" during sessions, where incumbent contestants are periodically replaced with fresh subjects from the waiting room. Specifically, each contestants' chance of being replaced is inversely related to their payoff relative to the average payoffs of other contestants. We compare this **Pressure**- treatment condition to a **No Pressure**-control condition where the replacement of active participants by new entrants is randomly determined and thus independent of payoffs.

Our **Pressure**-condition thus resembles the settings of *evolutionary game theory* (Weibull 1997, Nowak 2006, Sandholm 2010), which has successfully modeled both economic- and biological-selection pressures. As in evolutionary game theory, the relative payoffs of subjects serve as a *fitness basis* for determination of their (expected) lifespan in the experiment. Differently from evolutionary game theory, where players are *hard-wired* to play a fixed strategy, the human subjects in our experiment are not committed to a strategy, and they can strategically and deliberately respond to evolutionary selection pressure as the repeated contest unfolds over time. In particular, stage-game payoffs in the Tullock contest lead to a *mixed-motive game*, where the chance of surviving to play additional contests has to be traded off against the expected payoffs that can be earned in each contest round. This allows us to study how the pressure for survival faced by real-life economic agents interacts with individual payoff maximization-incentives as traditionally considered in theoretical- and experimental-economics.

Indeed, the setting we study has real-world counterparts. For instance it is similar to "rank and yank" programs at technology firms (e.g., GE, Microsoft, Amazon), where employees are ranked based on their performance and the lowest-performing employees – typically the bottom 10% – are either let go or reassigned to less critical roles. Similarly, the dictum "publish or perish" associated with university tenure decisions, has an element of performance–based selection of talent.

Surprisingly, and contrary to theoretical predictions, we find that selection pressure *decreases*

participants' competitiveness as measured by average investment levels across contests, relative to the **No Pressure**-control treatment. This happens because the pressure to survive exerts a strong, disciplining influence on participants' decision-making in the **Pressure**-treatment, with average investments closely approximating the survival-optimal level. In particular, a specifically simple behavioral rule (which we refer to as an "average unbeatable strategy", see Section 3) allows incumbent contestants under **Pressure** to all but ensure survival. By contrast, the absence of any connection between decision making and survival chances in the **No Pressure**-treatment leads to large fluctuations in investment levels, as well as to widespread and substantial over-investment beyond both profit- and survival-maximizing levels.

Strikingly, selection pressure does not merely redistribute profits to successful contestants. Rather, the average round payoffs for the entire population of contestants in the **Pressure**-treatment are increased relative to the **No Pressure**-treatment.

The remainder of this paper is organized as follows. Section 2 surveys the past experiments most similar to novel our selection-pressure experiments. Section 3 provides some theoretical background regarding profit maximization and survival in the Tullock contest. Section 4 describes the experimental design. Section 5 discusses the results. Section 2 discusses related experiments. Section 6 concludes.

2 Related Literature

While experimentalists have studied zero–sum games and contests (see, e.g., Dechenaux et al. 2015 for a survey), have paid subjects based on their relative performance, (e.g., Andreoni 1995), and have studied decision-making under induced time pressure (e.g., Kocher and Sutter 2006), stress (e.g., Starcke and Brand 2012) or other exacerbating factors (e.g., cognitive load, see Deck and Jahedi 2015), there is not usually any explicit *replacement* of subjects during an experimental study based on their performance relative to other subjects.

The only prior experiment that explicitly considers survival- vs. payoff-maximization incentives is by Oprea (2014). But he does so in a *non-strategic* setting: i.e., participants repeatedly withdraw payments from a stochastically renewing account, trading off additional earnings against the risk of depleting their account and going bankrupt. We suspect that the lack of experiments studying selection pressure is due to the logistical difficulties of implementing replacement of subjects in traditional laboratory environments. These difficulties, however, have recently been alleviated by the ability to conduct online sessions with remotely connected subjects as we do in this study.

The closest contest experiment to this paper is by Brookins et al. (2021). They compare indefinitely repeated 2-player contests against finitely repeated contests of the same expected duration. In their indefinitely repeated contest, cooperative behavior (both players invest 0) is sustainable via trigger strategies, whereas it unravels by backward induction in the finitely repeated game. In our study, selection events are randomly determined so that both our **Pressure**- and **No Pressure**-

treatments can be viewed as a kind of indefinitely repeated game. However, unlike standard random termination, only some players exit after the terminal round, while others may continue, complicating the use of history-dependent strategies such as grim trigger.

Several experiments have implemented overlapping generation environments in the laboratory, (see, e.g., Marimon and Sunder 1993, Offerman et al. 2001, Duffy and Lafky 2016) where inexperienced "young" agents replace "old" experienced agents, but in this case the birth-and-death process is fully *deterministic* and is *not* based on relative payoffs as we propose here. Further, in some of these studies subjects are repeatedly recycled through the generational process (or "born again") because of the logistical difficulties of bringing in new subjects while forcing others to leave.

Lastly, numerous experiments (e.g. Huck et al. 1999, Offerman et al. 2002, Friedman et al. 2015) have studied selection by imitation in environments involving unknown, partially known, or complex payoff structures. By contrast, this experiment is the first to induce selection pressure through the *replacement* of subjects.

3 Theory

A wide range of competitive interactions in biological and socioeconomic environments share the incentive structure of rent-seeking contests (Tullock 1980). Examples include the selection of sexual partners, deployment of forces in military conflicts, R&D-races between firms, competition for promotion between employees, litigation, political lobbying, fundraising, and charitable auctions.

Formally, consider a population of n active players competing for a resource of common value $V > 0$. Each player i chooses an effort or investment amount $x_i \geq 0$. Given an individual investment x_i and a vector of opponents' investments $x_{-i} = (x_j)_{j \neq i}$, players are deterministically awarded shares in the resource,[1] with i's share following:

$$p_i(x_i, x_{-i}) = \begin{cases} \frac{x_i}{\sum_j x_j}, & \text{if } \sum_j x_j \neq 0, \\ \frac{1}{n}, & \text{otherwise.} \end{cases}$$

Player i's payoffs are thus given by $\pi_i(x_i, x_{-i}) = p_i(x_i, x_{-i})V - x_i$. The period payoff maximization problem is:

$$\max_{x_i} \{\pi_i(x_i, x_{-i})\}$$

Maximization yields the best-response function:

$$x_i^{\pi}(x_{-i}) = \sqrt{\sum_{j \neq i} x_j V} - \sum_{j \neq i} x_j.$$

[1] A commonly used alternative implementation stochastically awards the full resource to one player. In this "winner-take all" implementation, $p_i(x_i, x_{-i})$ is the probability with which player i wins the resource. In our experiment, deterministic proportional allocation of resource shares based on relative investments was chosen over the stochastic allocation of the full resource to make the connection between investment decisions and survival chances in the repeated contest less noisy and more easy for subjects to comprehend. Theoretically, assuming risk neutral preferences, there should be no difference in equilibrium outcomes between these two methods of allocating the prize.

In the unique Nash equilibrium of this symmetric n-player game,

$$x_i^{NE} = \frac{n-1}{n^2}V.$$

Tullock contests belong to a class of games for which Alchian's (1950) intuition that evolutionary pressure changes the predictions of economic models holds true in a radical way (also see Hehenkamp et al. 2004): That is, a player seeking to maximize their chance of survival and, hence, maximizing their payoff relative to the group average will choose a strictly higher investment level than does a player who is simply maximizing period profits. In particular, the equilibrium among players maximizing relative payoffs– Schaffer's (1988) finite population ESS – implies strictly higher investment levels than the standard Nash equilibrium.[2]

To see this, consider the maximization problem

$$\max_{x_i}\left\{\pi_i(x_i, x_{-i}) - \frac{1}{n}\sum_i \pi_i(x_i, x_{-i})\right\} \sim \max_{x_i}\left\{\pi_i(x_i, x_{-i}) - \frac{1}{n-1}\sum_{j\neq i}\pi_j(x_j, x_{-j})\right\}.$$

Noting that $x_i \neq 0$ is not optimal at $\sum_{j\neq i} x_j = 0$,[3] i's relative-payoff best-response function x_i^s follows from taking first-order conditions:[4]

$$x_i^s(x_{-i}) = \sqrt{\frac{n}{n-1}\sum_{j\neq i} x_j V} - \sum_{j\neq i} x_j.$$

Under relative payoff maximization, investment choices are uniformly higher than under profit maximization, i.e., $x_i^s(x_{-i}) > x_i^\pi(x_{-i})$ for all x_{-i}. And, in particular, the finite-population ESS x^{ESS} (equilibrium among relative payoff-maximizing players), implies strictly higher investment levels than under the standard (profit-maximizing) Nash equilibrium:

$$x^{ESS} = \frac{V}{n} > x^{NE} = \frac{n-1}{n^2}V.$$

Hence, Tullock contests provide an ideal incentive structure to observe experimental subjects trading off profit maximization- against survival-incentives.[5]

[2] As seen below, the difference between Nash equilibrium and finite-population ESS is decreasing in n. In particular, for an infinite number of players, each with vanishing influence on aggregate profits, the difference disappears altogether. This corresponds to the more widely known analysis of evolutionary stability for a *continuum* of players (Weibull 1997), in which ESS becomes a *refinement* of Nash equilibrium with further stability properties with respect to mutants making up a "small" share of the infinite population.

There also exists a class of games for which ESS and Nash equilibrium coincide for arbitrary finite numbers of players, see Hehenkamp et al. (2010).

[3] This follows from observing that i's relative payoff for $\sum_i x_i = 0$ is 0, whereas investing $0 < \varepsilon < V$ would yield a relative payoff of $V - \varepsilon$. A similar argument shows that $\sum_i x_i = 0$ never occurs among profit-maximizing contestants.

[4] The value function's second derivative is negative everywhere, showing that a local optimum derived in this way is, in fact, global. This is also true for standard profit maximization in the Tullock contest.

[5] More generally, such incentives obtain for quasisubmodular aggregative games as in Alós-Ferrer and Ania (2005). Next to more general versions of Tullock contests (allowing for Tullock's-r in the range $0 < r < \frac{n}{n-1}$), this includes

In addition, ESS-play in the n-player Tullock contest has an extra, previously unstudied, stability property. That is, strategy x^{ESS} is uniquely "unbeatable on average":[6]

Proposition 3.1. *(ESS is uniquely unbeatable on average)*
$x^{ESS} = \frac{V}{n}$ *is the unique strategy in the Tullock contest such that*
$\pi_i(x^{ESS}, x_{-i}) - \frac{1}{n-1}\pi_j(x^{ESS}, x_{-i}) \geq 0$ *for all* x_{-i}.

Proof. To see that x^{ESS} is unbeatable on average, note that

$$\Pi_i(x^{ESS}, x_{-i}) - \frac{1}{n-1}\sum_{j\neq i}\Pi_j(x^{ESS}, x_{-i}) = \left(\frac{V}{n} - \frac{\sum_{j\neq i} x_j}{n-1}\right)^2 \frac{n-1}{V/n + \sum_{j\neq i} x_j} \geq 0.$$

To see that x^{ESS} is *uniquely* unbeatable on average, let x_{-i}^{ESS} be the $n-1$-row vector of ones multiplied by x^{ESS}, and note

$$\Pi_i(x_i, x_{-i}^{ESS}) - \frac{1}{n-1}\sum_{j\neq i}\Pi_j(x_i, x_{-i}^{ESS}) = -\frac{(x^{ESS} - x_i)^2}{x} \leq 0$$

with equality iff $x_i = x^{ESS}$. □

Thus, independent of other contestants' behavior, playing x^{ESS} guarantees a (weakly) positive relative payoff. While this is not sufficient to guarantee survival in a general stochastic setting, it *does* the job in our **Pressure**-treatment described below, where incumbent contestants face a risk of replacement iff their payoffs are below the population average. Thus, in our repeated contest experiment described below, we expect that x^{ESS} will be a salient choice for participants focusing on surviving in our repeated contest experiment. Furthermore, to the extent that participants pick up the average unbeatability of x^{ESS}, we expect widespread investments at that level and little change of investment levels around x^{ESS} in reaction to other participants' investment behavior.

4 Experimental Design

The experimental design implements selection pressure in indefinitely repeated Tullock contests. Specifically, we consider a population of 4 active participants who repeatedly compete for a resource of value $V = 100$. The contest function is the one from Section 3, with contestants choosing investments amounts from a fixed budget of $X = V$ in each round. Any unused investment budget as well as any contest winnings contribute to per-round profits but investment budgets are non-transferable across rounds.

popular games featuring strategic substitutes such as Cournot competition, and the Tragedy of the Commons. While all of these games would be suitable in terms of featuring the trade-off described above, x^{ESS} is not necessarily "unbeatable on average" as described below.

[6] This property was first suggested by Possajenikov (2023). He proves that the finite-population ESS is unbeatable in 2-player Cournot games with decreasing demand function. In particular, this includes 2-player Tullock contests with Tullock $r \leq \frac{n}{n-1}$. Possajenikov's results do extend to average unbeatability in some $n > 2$-player versions of these games. In particular, the finite-population ESS is unbeatable on average for $n > 2$-player Tullock contests with $r \leq 1$.

This puts the ESS-investment for the one-shot contest at $x^{ESS} = 25$, whereas the Nash-investment would be $x^N = 18.75$. The ESS implies full dissipation $\frac{nx^{ESS}}{V} = 1$, whereas there would be underdissipation $\frac{nx^N}{V} = \frac{3}{4}$ in the Nash equilibrium.

The Tullock contest is repeated for an indefinite number of rounds. Specifically, there is a constant, known–to–all probability, $\rho = .1$, that a *replacement event* occurs. At each replacement event, one contestant is eliminated and is replaced by a new subject from the waiting room who has not previously participated in the experiment.

Replacement events also govern the termination of the game. Specifically, we draw game lengths from a negative binomial distribution with 11 replacement events at probability $\rho = .1$, where the 11th replacement event terminates the game. Hence, each of our sessions features 10 replacements of a contestant before the game's termination, with a random number of intermittent rounds between any two replacement events. The number of replacement events is not disclosed to participants.[7] All game configurations (i.e., numbers of intermittent rounds between replacements) are pre-drawn and balanced across treatments.

We employ two distinct treatments, corresponding to the extremes of no selection pressure and deterministic selection based on relative payoffs. In our first **No-Pressure**-control treatment, the replacement of contestants is fully random. That is, conditional on a replacement event occurring, each of the contestants is selected for replacement with probability $\frac{1}{4}$, independent of their decisions or payoffs, and this fact is known to all. In our second **Pressure**-treatment, we consider deterministic selection. That is, conditional on a replacement event occurring, (one of) the worst performing active participant(s) will be selected for replacement with certainty, and this fact is again known to all. Performance is measured based on relative payoffs in the contest round immediately preceding the replacement event. Performance was evaluated for a single contest's payoffs (rather than the sum or average of contests between replacements) in order to avoid portfolio effects across contests, e.g., a contestant building up a "stock" of above-average (below-average) outcomes might pay less (more) attention to late contests compared to early contests.[8] In the case of multiple worst-performers, random tie-breaking is used to select a contestant for replacement.

Figure 1 below shows the decision interface used in the experiment. Participants used a slider to submit investment amounts in lab dollars L$ from their budget of L$100 in each contest round.

[7] From the contestant's perspective, the game features an unknown number of replacements arriving at rate $\rho = .1$. Statistically, the game's unknown length from the participant's perspective can be modeled as a geometric process with an additional, uncertain parameter $\delta \in (0, 1)$ determining termination.

[8] Given that only a single round is relevant for replacement and that replacement events arrive randomly, using the last round before a replacement event to evaluate performance does not alter incentives relative to selecting one round at random. Using the last round has the added benefit that payoff-related feedback about selection events is identical to the feedback provided when no selection event occurs. See the subsequent paragraph for details.

They used a second slider (above the investment choice slider) to specify their expectation of the average investment amount of their opponents. As an alternative to the sliders, contestants could directly input investments and predictions in a field above the respective slider. A dynamically updating pie chart showed the expected split of the resource given a subject's investment and their prediction of opponents' average investment amounts. The expected share of the resource and the resulting expected payoff was displayed at the bottom of the screen. By using this prediction tool, it is possible for players to discover the unbeatable on average strategy.

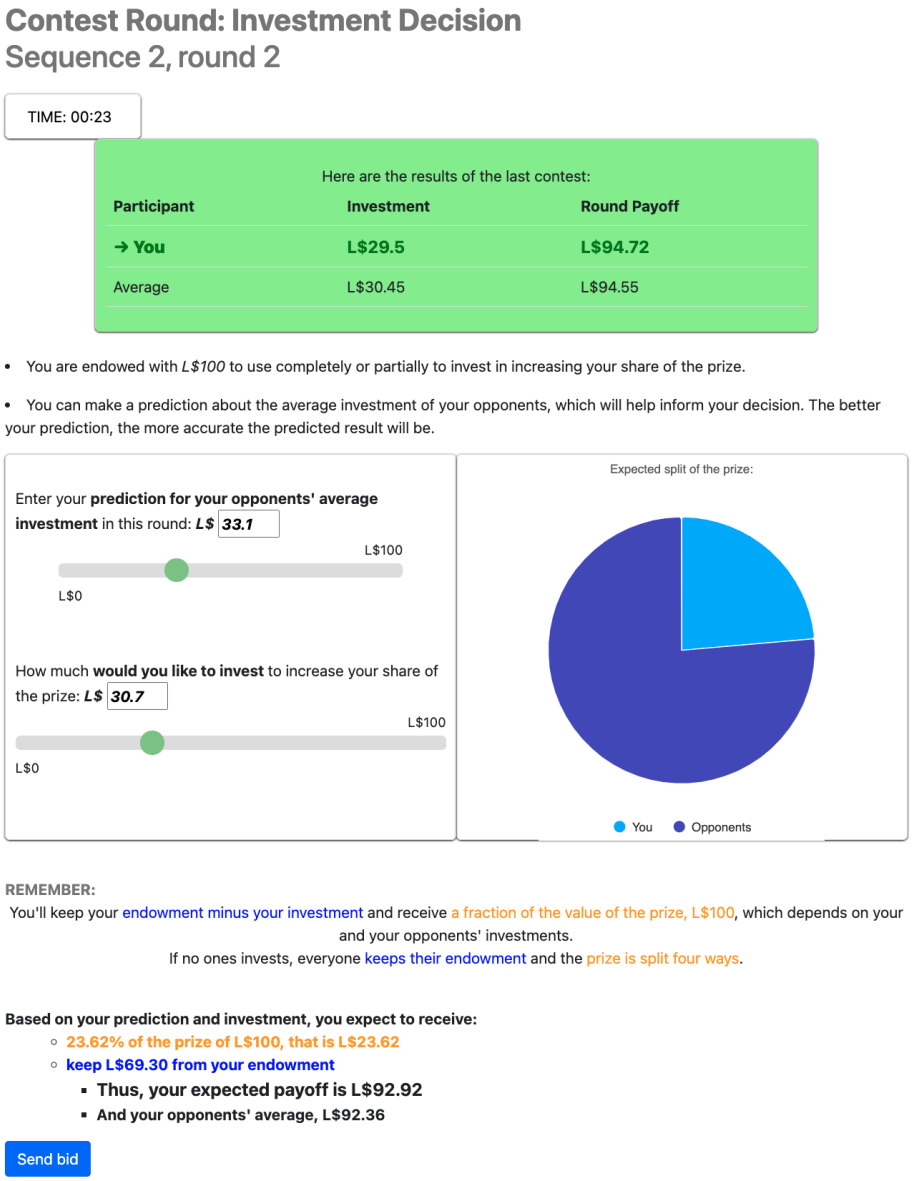

Figure 1: **Decision screen used in the experiment**

In each contest round, participants had a time limit of 30 seconds to make their decision. Additionally, and where a contestant was not replaced by a new subject, previous-round inputs

were used as the default setting for the next round. Importantly, the time limit was soft; there were no consequences to violating the time limit and, in particular, the default settings were not submitted without a contestant's active confirmation.

Note that the prediction of other contestants' average investment was unincentivized. This feature was added to assist subjects in making their investment decisions. While participants were not paid separately for these predictions (to avoid complicating the instructions and incentives) the utility of an accurate prediction for subsequent decision-making can be viewed as *endogenously* incentivizing these predictions.

After the initial round, continuing contestants in both treatments are shown their own investment and payoff, as well as the average investment and payoffs of the other contestants in the previous round. Throughout a session, own outcomes and investments as well as population averages were observed by active contestants after each round. Importantly, we did not furnish new entrants with historical data concerning prior gameplay, aiming to ensure that each player's history was solely constructed from their own, direct experiences.[9] In addition to the previous round's results, contestants were informed each time a replacement event occurred, including when they were not selected for replacement.

Subjects were recruited from UC Irvine's ESSL student subject pool and from UC Santa Cruz's LEEPS student subject pool to remotely participate in our study. We have data for 10 sessions of each treatment (20 sessions in total) with 14 subjects per treatment, or 280 subjects in total.

As described above, sessions were run with a constant number of 11 replacement cycles (with the final replacement event terminating the game) and random numbers of rounds in between replacement events. Sessions lasted around 2 hours, though subjects were instructed that a session could last up to 3 hours (180 minutes).[10] Ten allocations of rounds were pre-drawn, with each allocation being implemented for one session of the **Pressure**- and one session of the **No Pressure**-treatment. Table 1 below reports the number of rounds to each replacement cycle in the ten allocations. This design allows for stochastic variation in the number of rounds between selection events, while the pairing of treatments to each allocation ensures that the randomness is balanced between the two treatments. The average number of rounds per session-pair was 96.4.

The experiment was computerized and programmed using oTree (Chen et al., 2016). All subjects were sent remote links to the study at the start of a session. After opening these links, the first page asked subjects permission to enable notifications. Each session started with 4 active subjects making choices in a 4-player contest. Subjects yet to enter the session were instructed to wait patiently; a

[9] This approach aligns with the findings of Malmendier and Nagel (2011) that individuals' expectations are predominantly shaped by their personal lived experiences.

[10] We chose to have just 10 replacement events (11 cycles) as we did not want to make the duration of the experiment too burdensome for subjects who began their participation in the first cycle, and who may have survived many or all 10 replacement events. A total of 11 subjects in the experiment started in the first cycle and went on to survive the entire experiment (4 subjects in **No Pressure** and 7 subjects in **Pressure**).

timer on their screens indicated the estimated time until their participation. At some time prior to their entrance into the study, a notification and sound went off on these subjects' computer screens to alert them that their participation would begin soon. At that stage, subjects were presented experimental instructions for their treatment and had to complete a related comprehension quiz. The full instructions and quizzes are shown in Appendix A. After completing the quiz, a subject entered the game following a replacement event. In this manner, all subjects read instructions at the same time, just prior to their participation. The subject who was removed from the session at each replacement event either randomly (**No Pressure**) or based on relative payoff (**Pressure**) was informed of their removal. They then had to answer an exit questionnaire that is shown in A.11. In this questionnaire, subjects provided demographic information, their educational background and self-assessed measures of risk, patience, and competitiveness. They also answered four cognitive reflection test (CRT) questions. After that, they were told their payoff from the study, and they were no longer able to make decisions in the experiment; once participation was over, subjects were free to close their study links and leave the session. They were paid their earnings electronically shortly after the session had concluded. In this manner, the population of active subjects was kept constant at 4 in every round of a session. At the end of the final cycle, instead of another replacement event, the session was declared over and all four remaining subjects were informed of this outcome (they did not know in advance which replacement cycle would result in termination of the session). They then answered the exit questionnaire and received payoffs in the same manner as the subjects who left before them.

Table 1: Number of contest rounds within each of the 10 replacement cycles, Sessions 1–20. Cycle 11 was the final cycle in each session.

Cycle	1	2	3	4	5	6	7	8	9	10	11	$\sum$
Sessions 1, 2	2	2	12	7	6	24	17	3	3	3	3	82
Sessions 3, 4	8	8	12	4	13	4	1	6	8	35	3	102
Sessions 5, 6	5	3	30	9	2	6	5	23	7	12	5	107
Sessions 7, 8	2	6	8	10	10	16	4	7	1	13	5	82
Sessions 9, 10	4	2	4	21	2	9	16	13	4	9	1	85
Sessions 11, 12	11	1	8	2	26	5	1	10	3	17	2	86
Sessions 13, 14	4	11	6	8	5	30	1	11	17	16	2	111
Sessions 15, 16	6	6	3	12	19	6	4	31	4	8	10	109
Sessions 17, 18	9	7	2	3	6	9	31	3	1	8	12	91
Sessions 19, 20	5	1	8	8	2	15	12	3	28	7	20	109

Subjects were given a budget of L$100 in every round of every cycle they participated in and could not make an investment in excess of that budget, so it was not possible for any subject to lose money in our experiment. Subjects were instructed that every $L20 earned in a Tullock contest

selected for payment amounted to $1 in earnings. In addition to a $10 show-up fee, participants were paid their earnings from the last round of *each* replacement cycle for which they were an active player, the same round used to evaluate their fitness in the **Pressure** treatment.[11] Thus, subjects in our **Pressure** treatment had an incentive to survive, as doing so enabled them to participate in more cycles and earn more money. Participants were paid electronically, using the platform of their choice, and earned an average of $25.44 including the $10 show-up fee, with a minimum payoff of $12.82 and a maximum of $68.02. We will further discuss payoff differences between the two treatments in the next section.

5 Main Results

5.1 Aggregate Patterns

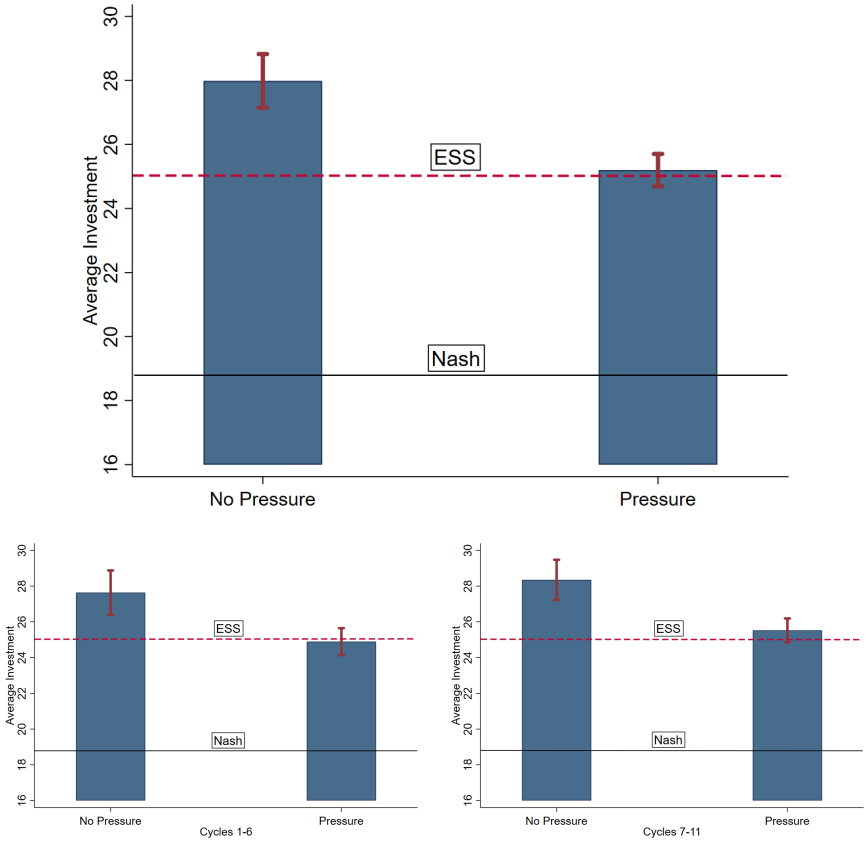

Figure 2: Average Investment Levels by Treatment. Bars: 99% confidence interval.

For an initial overview of the main results, the top panel of Figure 2 averages investment levels for **Pressure** and **No Pressure**. The resulting average investment level is significantly lower in the **Pressure** treatment than in the **No Pressure** treatment. Furthermore, investments significantly

[11] Recall that subjects did not know when the final round of a cycle would take place, so paying subjects' earnings in this final round is equivalent to randomly paying one of the rounds of the cycle.

exceed x^{NE} in both treatments, and they significantly exceed x^{ESS} in the **No Pressure** treatment. As seen in the bottom panels, these observations are persistent and hold up when restricting to early replacement cycles (1–6) and late replacement cycles (7–11).

Table 2 numerically reproduces these comparisons of investment levels. In addition, it also reveals that the *spread* of investments made in the **No Pressure** as measured by their standard deviation is significantly higher than in **Pressure**. This finding is robust when restricting attention to early or late cycles.

Table 2: Investment Levels, Pressure vs. No Pressure

		Pressure	99% CI$^{(1)}$	No Pressure	99% CI$^{(1)}$	Nash	ESS
Total	Mean	25.20	[24.69, 25.70]	27.98	[27.14, 28.82]	19	25
	Std.dev.	12.16	[11.30, 13.09]	20.22	[19.40, 21.09]		
Early stage$^{(2)}$	Mean	24.89	[24.14, 25.64]	27.64	[26.40, 28.88]	19	25
	Std.dev.	12.98	[11.93, 14.14]	21.39	[20.19, 22.69]		
Late stage$^{(3)}$	Mean	25.52	[24.85, 26.19]	28.35	[27.22, 29.47]	19	25
	Std.dev.	11.23	[9.86, 12.80]	18.91	[17.83, 20.07]		

[1] Mean: 99% normal confidence interval; Std.dev.: 99% Bonett confidence interval.
[2] Replacement cycles 1–6.
[3] Replacement cycles 7–11.

Figure 3 plots average investments across the 10 sessions in each treatment by replacement cycle. After indistinguishable investment levels across treatments in the first cycles, investments in **Pressure** tend to display low variance and closely track the ESS-investment level. By contrast, investments in **No Pressure** are higher and more volatile, rarely falling below the ESS-level.

While the picture of higher investment levels and higher variance absent pressure is generally corroborated by average investment patterns for individual session pairs, there is significant session-level heterogeneity in investments patterns. In particular, significant movement and volatility in investment levels for both treatments tends to coincide with the entry of new contestants, suggesting a destabilizing influence of replacements especially in **No Pressure**. See the Appendix for average investment patterns across the 10 session pairs.

5.2 Investments, Lifespans and Profits

Figure 4 shows the distribution of investments across treatments. **Pressure** displays a high percentage of bids within 5 points of x^{ESS}, with close to 35% of investments in that bin. By contrast, less than 20% of **No Pressure**-participants' investments lie in that region. A two-sample Kolmogorov-Smirnov test rejects equality of investment distributions across treatments at all conventional levels

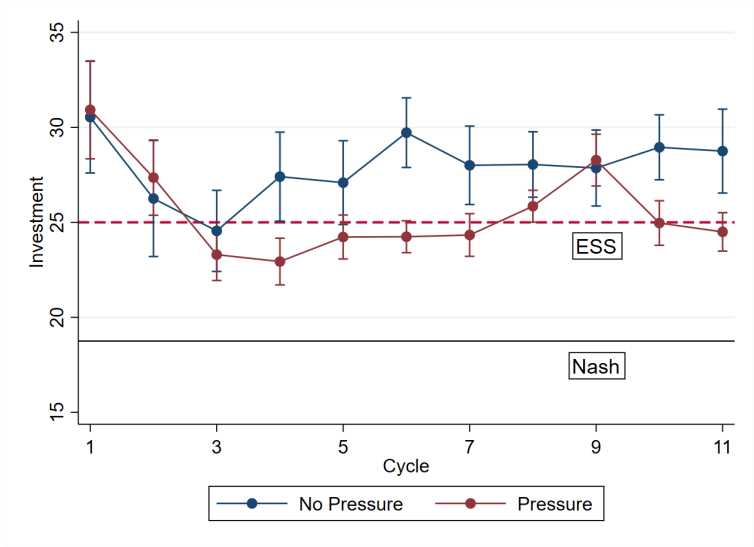

Figure 3: Average Investment Levels by Replacement Cycle.

(p=.000), while indicating that **No Pressure**-investments are significantly less concentrated than **Pressure**-investments.

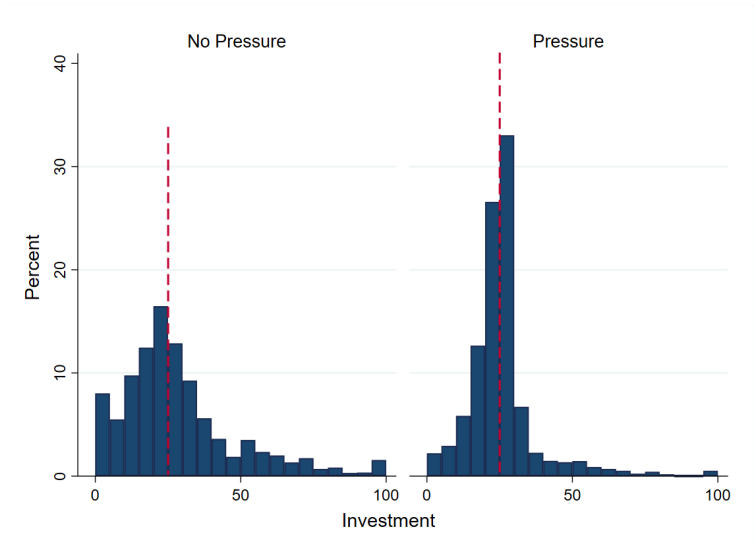

Figure 4: Investments by treatment. Red line: ESS.

Figure 5 shows the distributions of selection events survived by participants across treatments. For comparison, red dashes in the Figure indicate the theoretical asymptotic distribution of survived events absent selection pressure, that is, based on random replacement with probability $\rho = .1$. As seen in the figure, the **No Pressure**-realizations in our sample closely approximate the asymptotic distribution. By contrast, selection pressure leads to an increased share of participants surviving entire sessions. On the flip side, the share of participants surviving zero selection events in **Pressure** rises by a whopping 15% over **No Pressure**. The comparison suggests that **Pressure** enables a

small number of experienced players to survive most rounds of selection at the expense of less experienced participants.

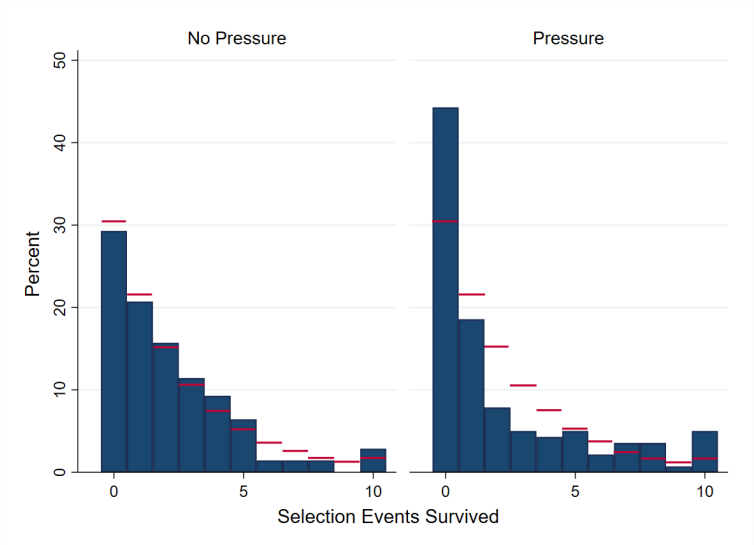

Figure 5: Selection events survived by treatment.

Since each additional survived replacement event opens up the chance for additional earnings, it is clear that the increased lifespan of some participants under **Pressure** also tends to increase their payoffs relative to average **No Pressure**-participants. Indeed, Table 3 below shows that **Pressure** increases the variance of final payoffs among participants, while both lowering minimum- and increasing maximum-earnings.

Table 3: Final Payoffs, US$ (Net of Showup Fee)

	Mean	Std.Dev.	Min	Max
No Pressure	15.28	10.82	3.06	55.33
Pressure	15.70	14.96	2.82	58.02

However, it turns out that **Pressure**-contestants are also doing better than **No Pressure**-contestants when looking at round payoffs. Specifically, **Pressure**-participants round payoffs average 99.88 points (99% CI: $[99.58, 100.18]$) – significantly more than their **No Pressure**-counterparts average round payoffs of 96.57 (99% CI: $[96.07, 97.08]$). This is further corroborated in Figure 6 below. The distribution of round payoffs in **Pressure** is significantly more concentrated around the ESS-payoff, with **No Pressure**-round payoffs displaying a more pronounced left tail. Indeed, a two-sample Kolmogorov-Smirnov test supports the observation that round payoffs under **No Pressure** tend to be smaller than payoffs under **Pressure** ($p < .001$).

Figure 7 compares average round payoffs by replacement cycle across treatments. As seen in the

figure, average round payoffs are initially indistinguishable across treatments, whereas **Pressure**-round payoffs tend to significantly exceed **No Pressure**-round payoffs in later cycles. Furthermore, **No Pressure**-round payoffs generally lie below the ESS-payoff and (hence) imply negative average returns on investments in the contest. By contrast, **Pressure**-round payoffs tend to exceed the ESS-payoff, implying mildly positive (but sub-Nash) average returns on investment in the contest for most replacement cycles.

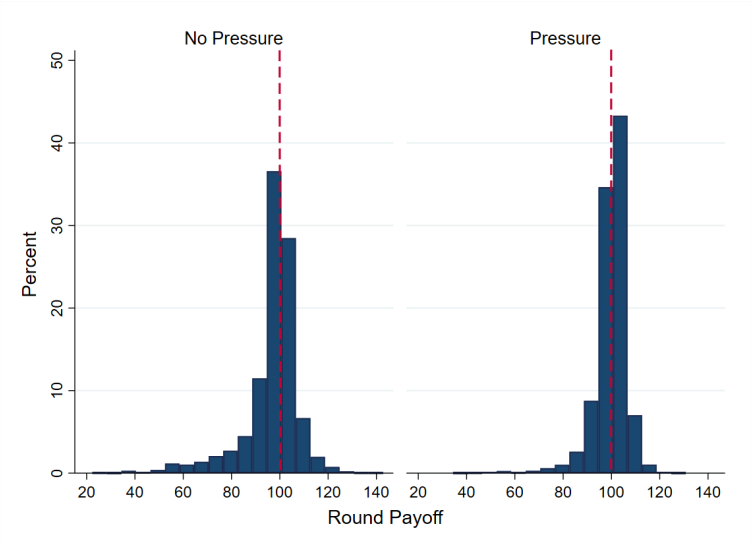

Figure 6: Distribution of Round Payoffs by Treatment. Red line: Round payoff at ESS.

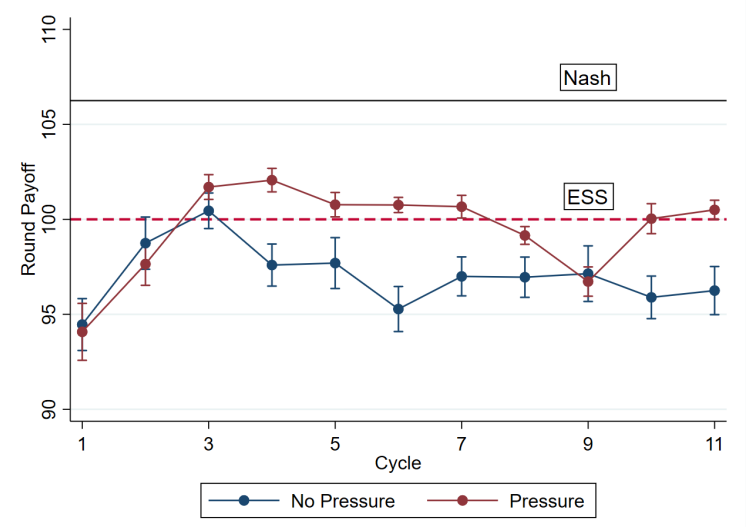

Figure 7: Distribution of Round Payoffs by Replacement Cycle.

In summary, selection pressure has a moderating effect on participants' investments in the contest, and this significantly improves round payoffs in **Pressure** as compared to **No Pressure**. In the next section, we will zoom in on the behavioral channels that lead to these differences in investment- and payoff-patterns across treatments.

5.3 Individual Behavior and Decision-Making

The last section reported main results at the aggregate level. In this section we look more closely at what subjects were doing at the *individual* level.

To begin, Figure 8 investigates the degree of stability in subjects' individual investment decisions, as measured by subject-level standard deviations of investments by replacement cycle.

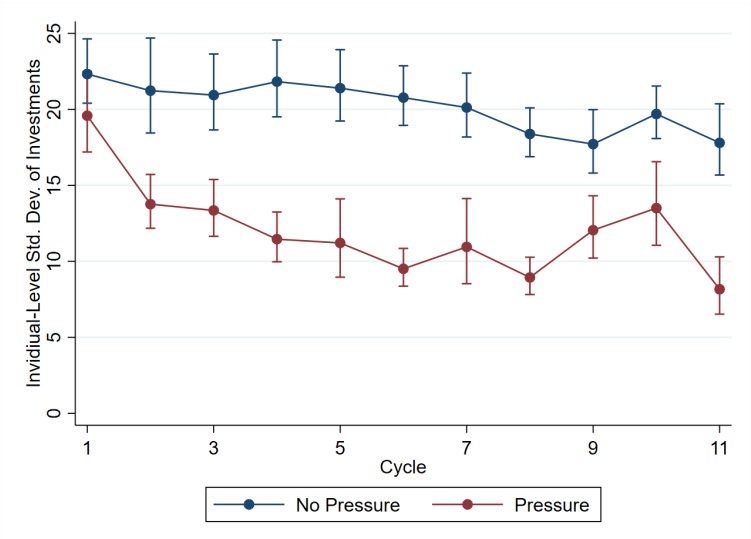

Figure 8: Individual-level Standard Deviations of Investments by Replacement Cycle.

As seen in the figure, within-cycle standard deviations of individual investments are large for **No Pressure**, generally ranging between one fifth and one fourth of the resource's value. By contrast, individual investments show less variation in **Pressure** ranging between 10-15% of the resource's value and sometimes even less. This indicates that selection pressure has a disciplining effect on individual behavior, causing **Pressure**-subjects to make more consistent investment decisions within a given replacement cycle.

Next, Figure 9 turns to the *drivers* of individual investment patterns. The figure examines the relationship between individual lifespans in the experiment and three summary measures of individual decision-making: average distance to the ESS-investment level, average distance to the best response, and average absolute prediction error.

As seen in the top panel, there is a direct relationship between longevity (selection event survived) in **Pressure** and increased ESS-play in that treatment, whereas average investments of long-lived contestants in **No Pressure** are unrelated to the survived number of selection events. This suggests that the higher incidence of near-ESS play in **Pressure** is driven by subjects adapting to the presence of selection pressure. Furthermore, as seen in the remaining panels **Pressure** also improves players' decision making as measured by their average distance to the profit-maximizing best response (bottom left Panel). The accuracy of successful players' predictions regarding the average investments of others is also greater in **Pressure** relative to **No Pressure** (bottom right Panel). However, running a joint regression of selection events survived under **Pressure** on distance

to ESS, distance to best response, and predictive accuracy shows that only the distance to ESS is a significant predictor of lifespan at the 1%-level (p<.0001), whereas distance to best response and predictive accuracy do not explain significant variation in lifespans (p=.042 and p=.896, respectively). (None of these three variables explain significant variation in lifespans in **No Pressure**.)

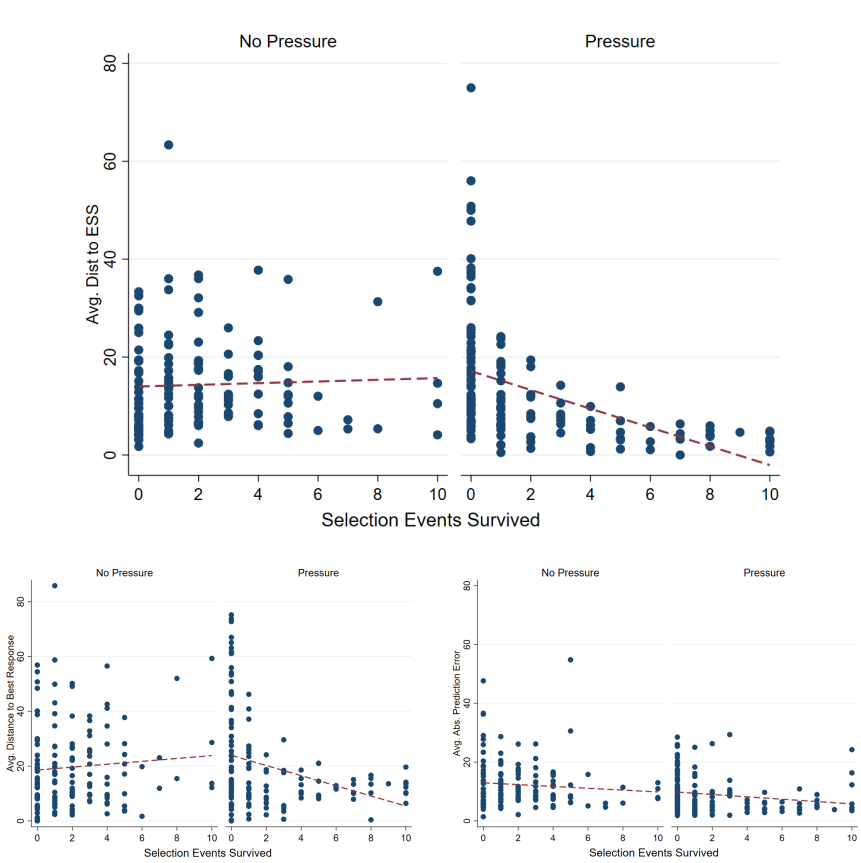

Figure 9: Decision-Making vs. Lifespan.

The Figure 9-patterns and the related regression results indicate that subjects in **Pressure** display a tendency to choose ESS-level investments that are independent of best-response behavior. To examine this further, Figure 10 investigates individual play-dynamics relative to the ESS. As seen in the left panel, average investments across replacement cycles are lower in **Pressure** than in **No Pressure** and they exhibit a significant decrease towards the ESS investment level, with no comparable decreasing pattern absent pressure.

At the same time, there is no trend towards ESS-play in either treatment as the Tullock contest gets repeated *within* cycles. This is seen in the right panel where average distance to the ESS is plotted by within-cycle contest rounds, averaged across all cycles.[12]

In combination these findings suggest that increased ESS-play is chiefly driven by subjects

[12]As the number of contest rounds increases, there are fewer and fewer cycles for which we observe that many rounds, with no cycle having more than 31 rounds in our sample. The figure therefore reports results up to contest round 19. Given the negative binomial distribution that we use to draw game lengths, this corresponds to the expected number of contest rounds for each cycle plus one standard deviation.

reacting to the selection pressure intervention, rather than by learning- or imitation-dynamics, which had been found to support ESS-play in previous experiments absent selection pressure (see, e.g., Friedman 1996, Huck et al. 1999, Offerman et al. 2002, Friedman et al. 2015).

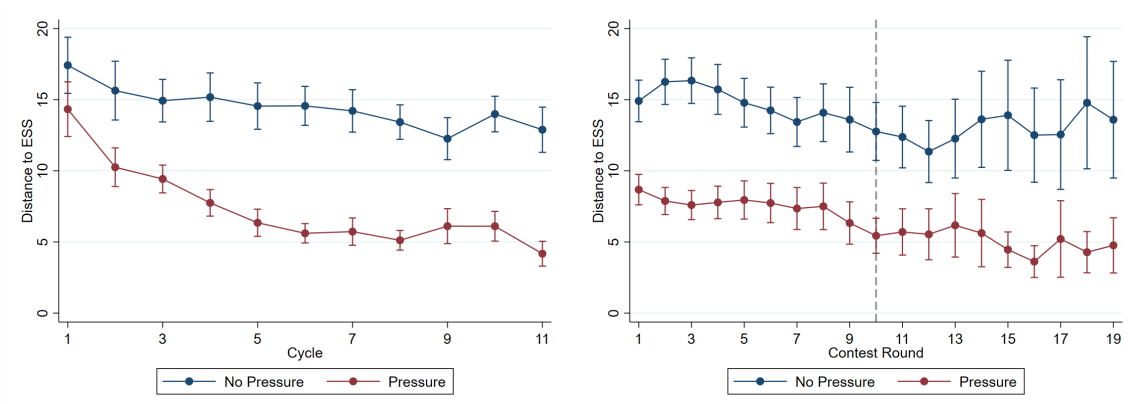

Figure 10: Dynamics of play vs. ESS. **Grey line:** Expected number of rounds per cycle.

Figure 11 below redoes the Figure 10-analysis with respect to **best response**-dynamics. As seen in the figure, while subjects in **Pressure** are closer to best-responding in most cycles and for most contest rounds within a cycle, no tendency towards increased best-response behavior is observed within or across cycles for either treatment. This is a first piece of evidence supporting that subjects tend to select the ESS-investment level not for optimizing reasons but based on a more rigid behavioral rule such as average unbeatability (also see Section 3).

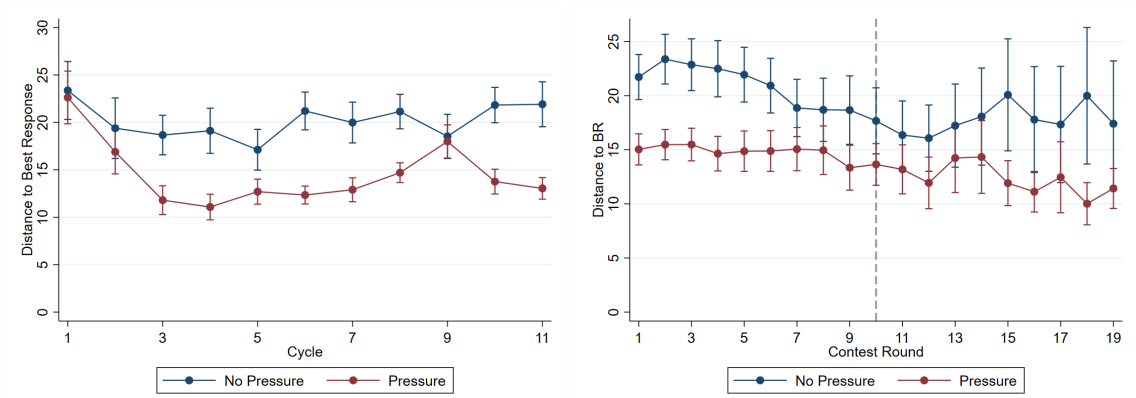

Figure 11: Dynamics of play vs. best response. **Grey line:** Expected number of rounds per cycle.

To better understand the decision rules followed by subjects, Figure 12 compares the distance of investments to ESS between entrant subjects starting to play in a given replacement cycle and incumbent subjects that have survived the previous replacement cycle.[13]

Strikingly, while there are no notable differences across treatments with respect to entrant

[13]Note that the Cycle 1-data is fully included in the Figure 12-top panels as all subjects in Cycle 1 are entrants. The results regarding entrant behavior across contest rounds reported in the top right panel are robust to excluding Cycle 1-data.

behavior (top panels), incumbent subjects in **Pressure** display both a tendency to approach ESS-investment levels *across* cycles and essentially constant investments in close proximity to the ESS *within* cycles. By contrast, **No Pressure**-incumbent subjects do not approach ESS-investments in later replacement cycles, and their within-cycle investments are significantly higher than the ESS-benchmark and incumbent investment in **Pressure**.

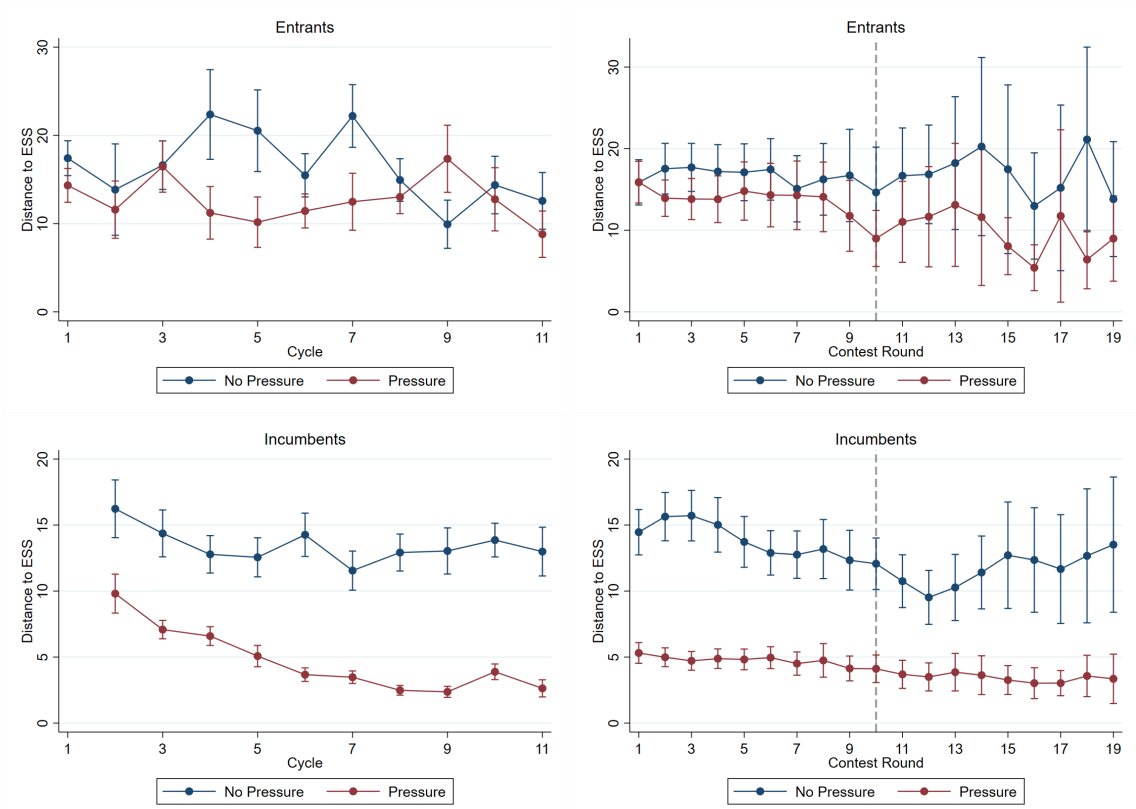

Figure 12: Dynamics of play vs. ESS. Entrant (top) and incumbents (bottom). **Grey line:** Expected number of rounds per cycle.

This demonstrates that selection pressure causes surviving subjects to adopt a rather rigid behavioral rule of investing close to the ESS-level, with fluctuations in investment for **Pressure** being chiefly driven by entrants and their decision-making. This rigid incumbent behavior is very much in line with the average unbeatability-property of the ESS which was demonstrated in Section 3. I.e., investing at the ESS-level guarantees survival in the **Pressure**-treatment while at least one other player invests at a different level. **Pressure**-incumbent subjects appear to exploit this property to maximize their lifespan in the experiment without much regard to other, potentially conflicting, objectives such as maximizing their round payoffs.

This behavioral rule "works" as long as other less experienced subjects do not pick up on the ESS's unbeatability quickly enough, leading them to face disproportionately higher odds of being eliminated from the repeated contest. And indeed, as seen in figure 13 below, the share of entrants

among eliminated subjects[14] is significantly higher under **Pressure** than under **No Pressure**, and it significantly exceeds the 25%-theoretical asymptotic share of entrants eliminated under random replacement that would obtain with an infinite sample of **No Pressure** sessions.

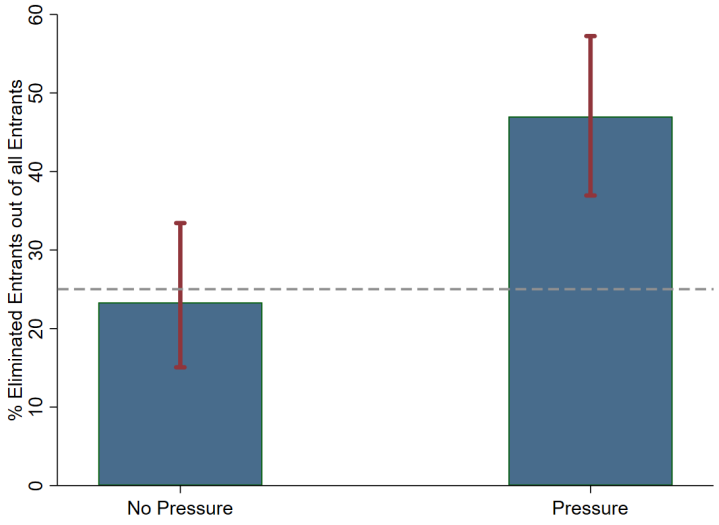

Figure 13: Share of entrants among eliminated contestants. **Grey line:** Asymptotic share of entrants replaced under random replacement.

5.4 Dissipation

The experimental literature studying Tullock contests (Dechenaux et al. 2015) *absent selection pressure* documents results that seem eerily supportive of our theoretical predictions *under selection pressure*. Starting with Millner and Pratt (1989), experiments have typically found substantial levels of *over-dissipation*. That is, contestants' aggregate investment in the contest $\sum_i x_i$ typically exceeds the value of the resource.

Remarkably, significant shares of participants invest consistent with evolutionarily stable behavior.[15] At the same time, there also tends to be a significant minority of subjects that go beyond what is supported by ESS-play, sometimes even exceeding the resource's monetary value (Sheremeta 2013, Mago et al. 2016, Gneezy and Smorodinsky 2006). In particular, over-dissipation rates average 15.55% across a large number of previous contest experiments surveyed by Sheremeta (2013), whereas the ESS would predict zero overdissipation (or, equivalently, full dissipation of the resource's value).

[14]For both treatments, we exclude Cycle 1 as there are no incumbents. Cycle 11 is excluded for **No Pressure**, whereas for **Pressure** we use round payoffs in the final round of Cycle 11 to determine which subjects would have survived had there been a 12th cycle. The results in Figure 13 are robust to excluding Cycle 11 data for both treatments.

[15]See, e.g., Figure 2 in Dechenaux et al. (2015), which reproduces findings from Sheremeta (2011). The Figure shows a high concentration of investments at the ESS-investment level of 30 points which is not further discussed by the authors.

The top panel of Figure 14 demonstrates that our **No Pressure** treatment generally replicates the amount of over-dissipation found in prior research (marked as 'Lit' in the figure), despite participants engaging in more complex, repeated contests in our study. By contrast, over-dissipation is drastically lower or even absent in the **Pressure**-treatment, approximating theoretical predictions under ESS-play and remaining significantly above Nash-equilibrium levels (labeled ESS and Nash in the table). These findings are robust when restricting to early and late cycles, see the bottom panels of Figure 14.

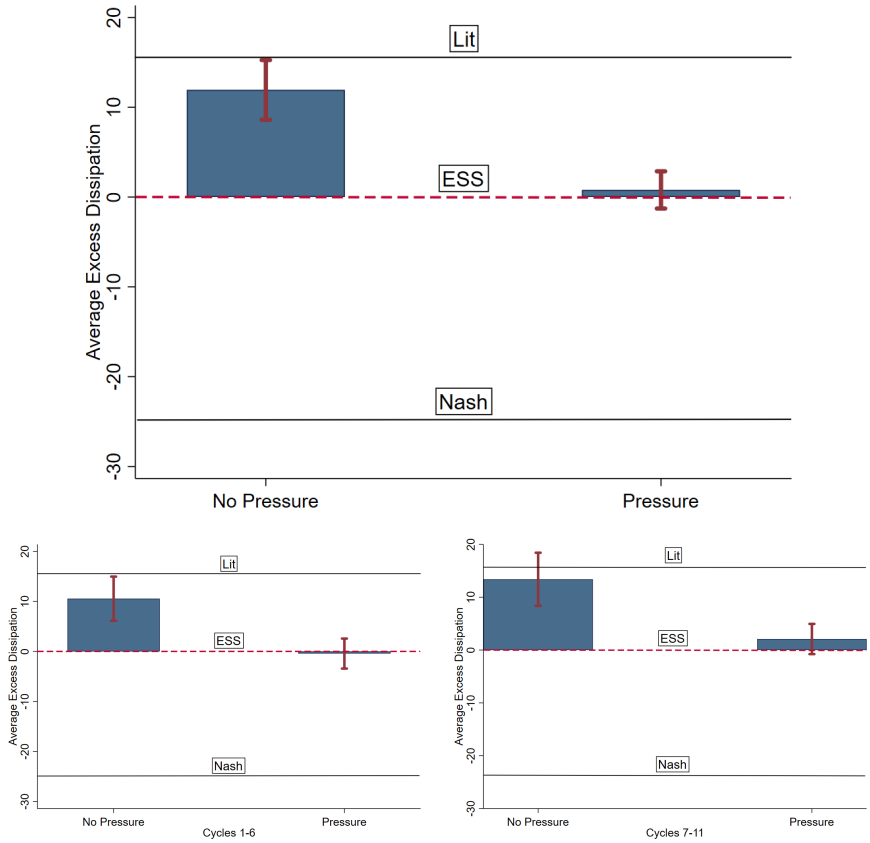

Figure 14: Average Excess Dissipation by Treatment. Bars: 99% confidence interval.

As seen in Figure 15, these findings generally hold up at the cycle level once incumbent contestants are sufficiently experienced.

The findings regarding dissipation suggest that large rates of over-dissipation reported in previous experiments are at least partially driven by participants' singular focus on monetary earnings in the experimental setting. By contrast, the threat of performance-based replacement faced by contestants in our **Pressure**-treatment leads to more modest investments. Moreover, **Pressure**-investments are well-approximated by ESS-play that would theoretically maximize decision-makers' survival chances.

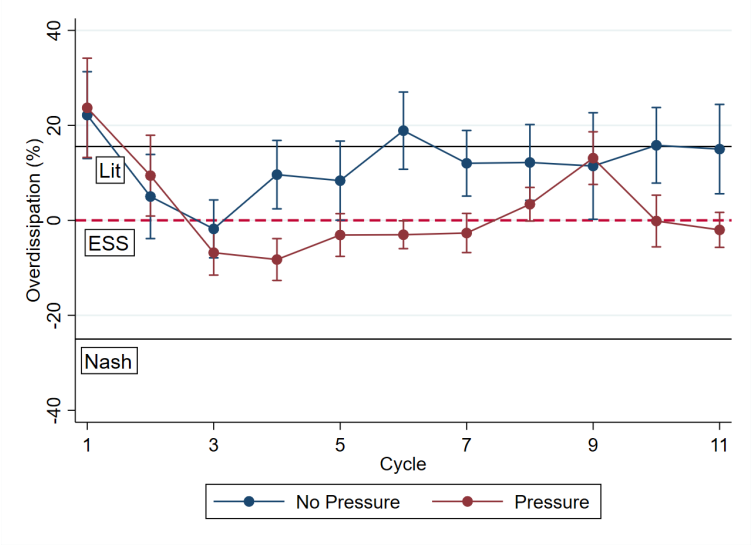

Figure 15: Dissipation by Replacement Cycle.

5.5 Individual Characteristics and Effects of Selection Pressure

This section considers demographics and other survey measures collected in the post-experiment questionnaire and explores the relationship of this data to decision-making in the two treatments.

To begin, Table 4 summarizes subjects' responses to the demographic- and survey-questions and compares the means and standard deviations of their responses across treatments. No significant differences are found between subjects assigned to the two treatment conditions.

Table 4: Overview of Survey and Demographics

	Total		No Pressure			Pressure		
Variable	Mean	Std.Dev.	Mean	Std.Dev.	99% CI	Mean	Std.Dev.	99% CI
Age	21.018	3.021	21.100	2.968	[20.445, 21.755]	20.936	3.082	[20.255, 21.616]
Gender	.655	.473	.632	.478	[.527, .738]	.679	.469	[.575, .782]
GPA	3.521	.460	3.457	.533	[3.340, 3.575]	3.585	.364	[3.504, 3.665]
Quant	6.789	6.238	7.221	7.024	[5.671, 8.772]	6.357	5.328	[5.181, 7.533]
CRT	2.336	1.279	2.279	1.309	[1.990, 2.567]	2.393	1.251	[2.117, 2.669]
Risk	4.268	1.494	4.079	1.532	[3.740, 4.417]	4.457	1.436	[4.140, 4.774]
Time Pref.	4.900	1.463	4.850	1.596	[4.498, 5.202]	4.950	1.321	[4.658, 5.242]
Competitiveness	4.586	1.802	4.571	1.718	[4.192, 4.951]	4.600	1.888	[4.183, 5.017]

Notes: *CI* is 99% normal confidence interval; *Gender* takes value 1 for female subjects, value .5 for non-binary subjects, and value 0 for male subjects; *Quant* is number of economics-, statistics-, and math-courses taken; *CRT* is score out of 4 on cognitive reflection test; *Risk* is 7-point Likert scale measure of willingness to take risks; *Time Pref.* is 7-point Likert scale measure of willingness to incur costs today for future benefits; *Competitiveness* is 7-point likert scale measure of willingness to compete.

Next, to investigate whether variations in demographic and survey responses influence behavior across treatments, Table 5 reports on a regression of: (1) investment amounts, (2) round payoffs, and (3) distance to the ESS on a treatment dummy for **Pressure** and on the demographic and

survey responses we collected from subjects at the end of the experiment. As this table reveals, the selection pressure treatment effect remains significant at the .01 level of significance for all three dependent variables when controlling for demographics and survey responses. Furthermore, there is a significant and consistent effect of subjects' self-reported willingness to take risks across all three dependent variables; a greater willingness to take risks increases investments and the distance to the ESS while lowering round payoffs. None of the other individual characteristics provide significant and consistent effects on investments, payoffs and distance to ESS. The gender dummy variable is significant for investments, but not for payoffs or distance to the ESS. These results suggest that our treatment interventions are the primary driving force behind the results that we obtain.

Table 5: Regression Analysis of the Impact of Demographics and Survey Responses on Investments, Payoffs and Distance to ESS

	(1) Investments		(2) Payoffs		(3) Distance to ESS	
	Coeff.	99% CI	Coeff.	99% CI	Coeff.	99% CI
Pressure (*d*)	-2.749	[-5.425, -.072]	2.886	[1.445, 4.327]	-7.536	[-9.485, -5.586]
Gender	3.021	[.069, 5.973]	-1.110	[-2.593, .373]	2.070	[-.018, 4.159]
GPA	1.194	[-1.746, 4.134]	-.748	[-2.380, .885]	1.597	[-.872, 4.066]
Quant	.257	[-.062, .577]	-.090	[-.266, .086]	.052	[-.143, .248]
CRT	.012	[-1.013, 1.037]	.011	[-.507, .529]	.056	[-.724, .835]
Risk	2.116	[1.076, 3.155]	-.951	[-1.531, -.371]	.819	[.034, 1.604]
Time Pref.	-.176	[-1.106, .754]	.247	[-.225, .719]	-.354	[-1.150, .442]
Competitiveness	-.652	[-1.435, .130]	.272	[-.219, .762]	-.269	[-.854, .317]
Constant	17.588	[1.845, 33.330]	98.633	[90.570, 106.696]	10.601	[-2.752, 23.954]
N	7,712		7,712		7,712	

(d) denotes dummy variable, effect of change from 0 to 1 reported.
Standard errors clustered at subject-cycle level.

6 Conclusion

Economists have long argued that selection pressure, – the struggle to survive – is an important driving force underlying a variety of economic decisions. Examples include investments in research and development, the acquisition of new skills or education, the adoption of new technologies, and competitive pricing in oligopolistic markets. In this paper, we have presented causal evidence from a controlled experimental setting – a first of its kind – regarding how individuals respond to such selection pressure. Our design allows us to directly observe the impact of selection pressure on decision-making in repeated Tullock contests. Our Pressure treatment is analogous to real-world

mechanisms like rank-and-yank policies and high-stakes performance evaluations.

We find that selection pressure due to performance-based replacement (mimicking evolutionary selection pressure) significantly impacts on contest investments and payoffs. Contestants in our Pressure treatment exhibit more moderated and survival-oriented investment strategies compared to contestants in the No Pressure control, where replacement is random. In particular, the Pressure group's investments align closely with the finite-population ESS of the Tullock contest. By contrast, investments in the No Pressure group are much higher, and they result in dissipation rates similar to what is found across a large number of previous experiments studying finitely repeated contests without selection pressure.

Furthermore, selection pressure is found to cause a notable decrease in the variability of investments within the Pressure treatment, suggesting that the threat of replacement can induce a more disciplined and consistent strategy among participants. Specifically, successful subjects in the Pressure treatment appear to adopt a rather rigid behavioral rule, which implements near ESS-investment levels independent of other contestants' behavior. This behavior appears reminiscent of recent theoretical results establishing an *unbeatability property* of the ESS in certain finite-population games. Disentangling unbeatability as a motivator for economic decision-making under selection pressure from other potential drivers such as (e.g.) the maximization of absolute or relative payoffs is an interesting avenue for future research.

Our findings are particularly relevant for understanding behaviors in high-stakes economic environments, such as corporate settings or competitive markets, where survival and success are closely tied to consistently outperforming benchmarks and peers. Our experiment shows that explicitly accounting for selection pressures in such settings leads to qualitatively different predictions.

Finally, it is important to note that our Pressure treatment results in higher overall payoffs and more efficient resource allocation among participants. This aligns with theories suggesting that competition and selection pressures can lead to more efficient outcomes in economic and biological systems. By contrast, the No Pressure condition, which lacks performance-based replacement, is characterized by greater fluctuations in investments and often suboptimal decision-making, mirroring less competitive economic environments or biological systems with low intensity of selection.

Our approach can be applied to many settings besides contests. For instance, we are currently applying our selection pressure design to investigate competition and collusion in oligopolistic industries. Other possible applications are to bargaining games or financial asset markets.

In conclusion, this research not only reaffirms the relevance of evolutionary theory to economic analysis, but it also expands our understanding of how survival pressures can shape competitive strategies in significant ways. The experimental methods introduced here open up new avenues for research into the adaptive behaviors of real-life economic agents under different types of selection pressures. In this manner, they enhance our understanding of the complex interplay between economic incentives and evolutionary dynamics.

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Appendix (For Online Publication)

A Experimental Instructions

The experiment was programmed using oTree (Chen et al., 2016). The following screenshots show the complete instructions for both treatment and related comprehension quizzes, as well as the post-experiment questionnaire.

A.1 First screen, Pressure Treatment

Instructions

Welcome to this experiment in decision-making.

- **General Information:**
  - Please plan on staying on your computer for up to 180 minutes.
  - This study consists of a random number of **Contest Rounds** in which 4 active subjects compete by bidding over the fraction of a prize they will receive.
  - At the end of each **Contest Round** with 10% probability a **Replacement Event** occurs. When such an event happens, the participant with the lowest payoff in that round is replaced with a new inexperienced participant.
  - The 4 participants in today's first **Contest Round** will be selected at random among a larger pool of enrolled participants and immediately receive detailed instructions. Instructions will remain the same for the entire session.
  - The rest of the enrolled subjects must wait and queue to later enter the study, and will receive the same detailed instructions, once their turn approaches. Information on the expected wait time to enter the study will be individually provided.
  - Participants waiting to later join the study are free to keep this window in the background and engage in other leisure activities on their device, but it is crucial that they keep an eye on the timer and queue position and also "Allow Notifications" in this page (button below) so that they can be informed when their turn approaches.
  - Before actively joining the study, waiting participants will receive a notification (even if they minimize this window) and hear (if they keep this window open in the background) the following sound ▶♫, after which they will have 45 seconds to confirm they are ready to join. Failure to confirm will relegate participants to the end of the queue.
- **Participants Compensation:**
  - After the end of your participation in the experiment, a US$10 show-up fee, plus your earnings from one random **Contest Round** for each **Replacement Event** you reached transformed to US dollars (US$) at a rate of US$1 per L$20, will be paid to you.
  - If you leave before being given permission by the experimenter, you will only be eligible for the US$10 show-up fee.

Please note: Throughout the experiment, endowments, investments and payoffs will always be expressed in Laboratory Dollars, L$.

→ Please Allow Notifications to Continue

A.2 First screen, No Pressure Treatment

Instructions

Welcome to this experiment in decision-making.

- **General Information:**
  - Please plan on staying on your computer for up to 180 minutes.
  - This study consists of a random number of **Contest Rounds** in which 4 active subjects compete by bidding over the fraction of a prize they will receive.
  - At the end of each **Contest Round** with 10% probability a **Replacement Event** occurs. When such an event happens, one participant is randomly replaced with a new inexperienced participant.
  - The 4 participants in today's first **Contest Round** will be selected at random among a larger pool of enrolled participants and immediately receive detailed instructions. Instructions will remain the same for the entire session.
  - The rest of the enrolled subjects must wait and queue to later enter the study, and will receive the same detailed instructions, once their turn approaches. Information on the expected wait time to enter the study will be individually provided.
  - Participants waiting to later join the study are free to keep this window in the background and engage in other leisure activities on their device, but it is crucial that they keep an eye on the timer and queue position and also "Allow Notifications" in this page (button below) so that they can be informed when their turn approaches.
  - Before actively joining the study, waiting participants will receive a notification (even if they minimize this window) and hear (if they keep this window open in the background) the following sound ▶♫, after which they will have 45 seconds to confirm they are ready to join. Failure to confirm will relegate participants to the end of the queue.
- **Participants Compensation:**
  - After the end of your participation in the experiment, a US$10 show-up fee, plus your earnings from one random **Contest Round** for each **Replacement Event** you reached transformed to US dollars (US$) at a rate of US$1 per L$20, will be paid to you.
  - If you leave before being given permission by the experimenter, you will only be eligible for the US$10 show-up fee.

Please note: Throughout the experiment, endowments, investments and payoffs will always be expressed in Laboratory Dollars, L$.

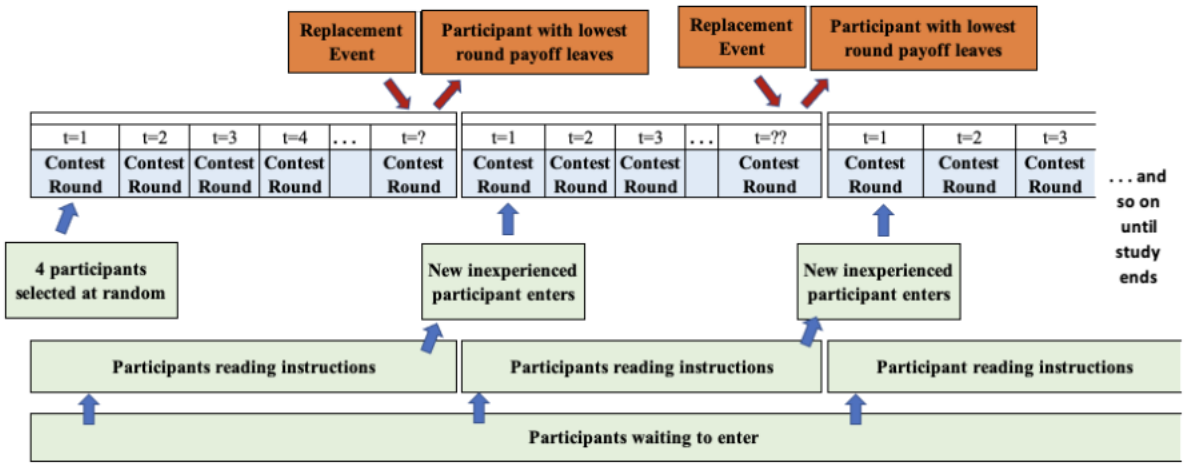
→ Please Allow Notifications to Continue

A.3 Second screen, Pressure Treatment

Instructions: Structure of the Study

Read these instructions carefully. You will have to successfully answer some questions that check your understanding of the instructions before you can proceed on to the study. If you have any questions let the instructor know via the zoom chat.

- **The structure of the study is illustrated below:**



- **Some Important Reminders**:
  - In each **Contest Round** the 4 active compete over the split of a prize.
  - At the end of each **Contest Round** with 10% probability a **Replacement Event** occurs, the total number of **Replacement Events** before the end of the study is unknown to participants.
  - When such an event happens, the participant with the lowest payoff in that round is replaced with a new inexperienced participant.
- **Participant Compensation**:
  - After the end of your participation in the experiment, a US$10 show-up fee, plus your earnings from one random **Contest Round** for each **Replacement Event** you reached transformed to US dollars (US$) at a rate of US$1 per L$20, will be paid to you.
  - Thus, the more **Replacement Events** you reach, the more payments you'll receive. Since you do not know which rounds will be chosen for payment, you will want to do your best in every round.
  - If you leave the session before being given permission by the experimenter, you will only be eligible for the US$10 show-up fee.

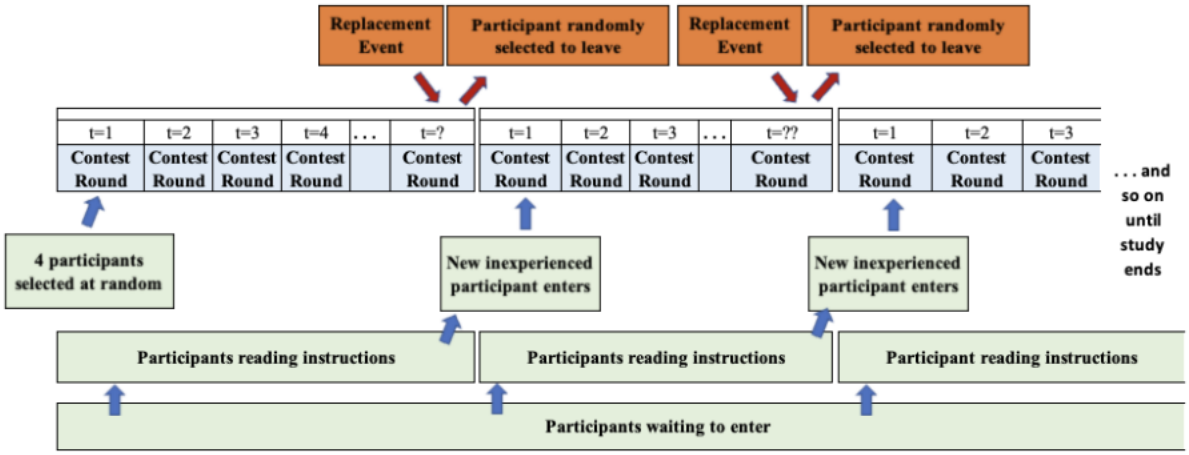
Next

A.4 Second screen, No Pressure Treatment

Instructions: Structure of the Study

Read these instructions carefully. You will have to successfully answer some questions that check your understanding of the instructions before you can proceed on to the study. If you have any questions let the instructor know via the zoom chat.

- **The structure of the study is illustrated below:**



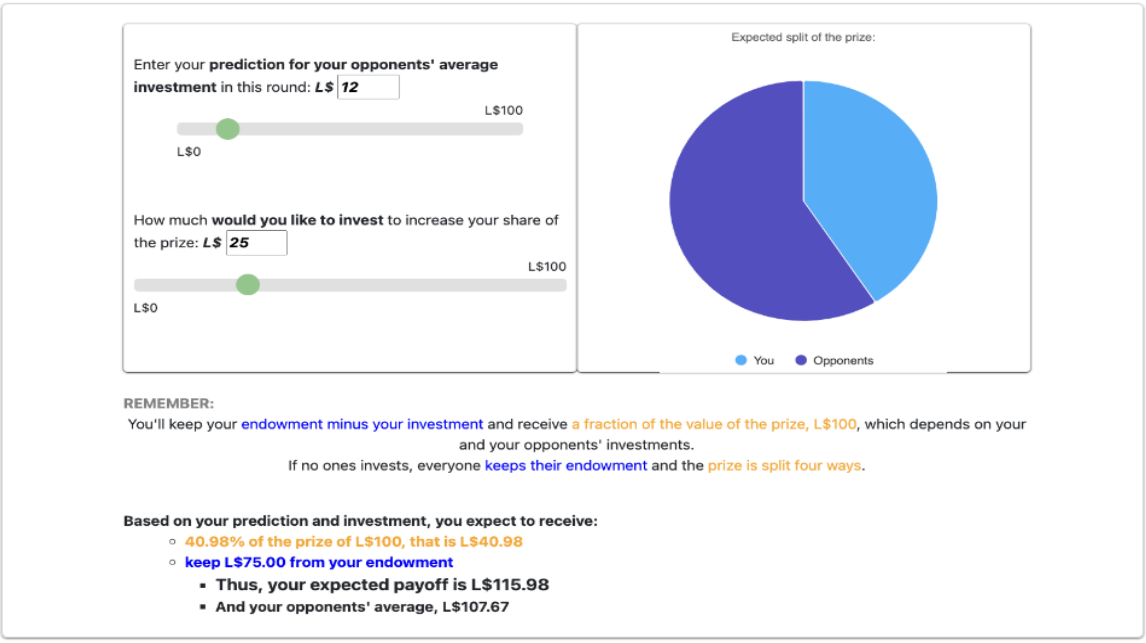
- **Some Important Reminders**:
  - In each **Contest Round** the 4 active compete over the split of a prize.
  - At the end of each **Contest Round** with 10% probability a **Replacement Event** occurs, the total number of **Replacement Events** before the end of the study is unknown to participants.
  - When such an event happens, one participant is randomly replaced with a new inexperienced participant.
- **Participant Compensation**:
  - After the end of your participation in the experiment, a US$10 show-up fee, plus your earnings from one random **Contest Round** for each **Replacement Event** you reached transformed to US dollars (US$) at a rate of US$1 per L$20, will be paid to you.
  - Thus, the more **Replacement Events** you reach, the more payments you'll receive. Since you do not know which rounds will be chosen for payment, you will want to do your best in every round.
  - If you leave the session before being given permission by the experimenter, you will only be eligible for the US$10 show-up fee.

Next

A.5 Third screen, Pressure Treatment

Instructions: Contest Rounds

- In each **Contest Round** that you participate in, you wll have to use the following interface to make your decisions (figure below):



- In each **Contest Round** you and the other 3 active participants (your opponents) compete in the following way:
  - You and your opponents are each endowed with *L$100* to use completely or partially to invest in increasing your share of a *L$100* prize.
  - The more you invest relative to your opponents, the higher the fraction of the prize you'll receive. In particular, if only one participant invests, they would take the whole prize independent of the invested amount. If all participants invest the same, the prize is equally split.
  - Formally, if participant i, j, k and l invest x_i, x_j, x_k and x_l, respectively, then the fraction, f_i of the prize that participant i would take would be equal to:

$$f_i(x_i, x_j, x_k, x_l) = \begin{cases} \frac{x_i}{x_i+x_j+x_k+x_l}, & \text{if } x_i + x_j + x_k + x_l \neq 0 \\ \frac{1}{4}, & \text{otherwise} \end{cases}$$

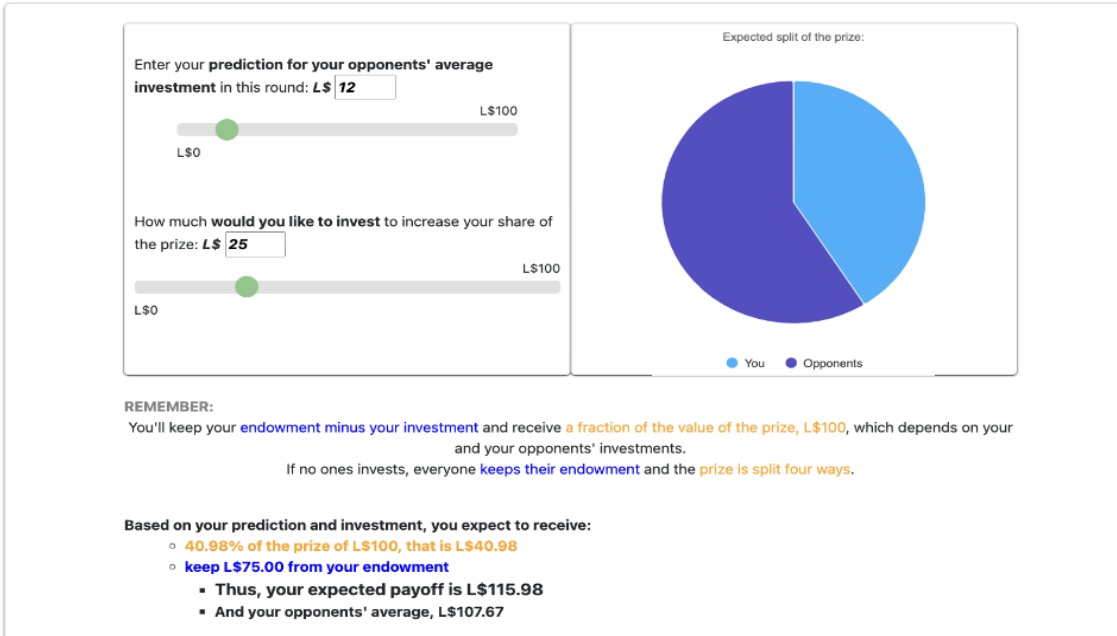
  - In addition to choosing your investment, you can make a prediction about the average investment of your opponents. This will help inform your decision. The better your prediction, the more accurate the predicted result will be.
  - On the left-hand side of your screen you'll have 2 sliders (and corresponding input boxes): one at the top that you can use for your prediction and one at the bottom which corresponds to your desired investment. Once you are happy with your prediction and your investment, you can press the "Submit" button.
  - On the right-hand side of your screen you'll see a pie chart that illustrates the expected outcome given your prediction and investment.
  - Whatever part of your endowment you do not invest is yours to keep and will be included in your round payoff along the fraction of the prize you receive. But note that you cannot save investment budgets across rounds: For each contest you will have *L$100* to invest, independent of what you invested in previous rounds.
  - **REMEMBER:** At the end of each **Contest Round** the probability of a **Replacement Event** is 10%. If a replacement event happens, the participant with the lowest payoff in that round will be asked to leave the study and replaced with an inexperienced participant.

Next

A.6 Third screen, No Pressure Treatment

Instructions: Contest Rounds

- In each **Contest Round** that you participate in, you wll have to use the following interface to make your decisions (figure below):



- In each **Contest Round** you and the other 3 active participants (your opponents) compete in the following way:
  - You and your opponents are each endowed with *L$100* to use completely or partially to invest in increasing your share of a *L$100* prize.
  - The more you invest relative to your opponents, the higher the fraction of the prize you'll receive. In particular, if only one participant invests, they would take the whole prize independent of the invested amount. If all participants invest the same, the prize is equally split.
  - Formally, if participant *i*, *j*, *k* and *l* invest x_i, x_j, x_k and x_l, respectively, then the fraction, f_i of the prize that participant *i* would take would be equal to:

$$f_i(x_i, x_j, x_k, x_l) = \begin{cases} \frac{x_i}{x_i+x_j+x_k+x_l}, & \text{if } x_i + x_j + x_k + x_l \neq 0 \\ \frac{1}{4}, & \text{otherwise} \end{cases}$$

  - In addition to choosing your investment, you can make a prediction about the average investment of your opponents. This will help inform your decision. The better your prediction, the more accurate the predicted result will be.
  - On the left-hand side of your screen you'll have 2 sliders (and corresponding input boxes): one at the top that you can use for your prediction and one at the bottom which corresponds to your desired investment. Once you are happy with your prediction and your investment, you can press the "Submit" button.
  - On the right-hand side of your screen you'll see a pie chart that illustrates the expected outcome given your prediction and investment.
  - Whatever part of your endowment you do not invest is yours to keep and will be included in your round payoff along the fraction of the prize you receive. But note that you cannot save investment budgets across rounds: For each contest you will have *L$100* to invest, independent of what you invested in previous rounds.
  - **REMEMBER:** At the end of each **Contest Round** the probability of a **Replacement Event** is 10%. If a replacement event happens, one participant at random is asked to leave the study and replaced with a new inexperienced participant.

Next

A.7 Quiz screen 1, Pressure Treatment

Instructions Quiz Part I

Before proceeding to the study, please answer the following questions regarding the instructions you just read:

1.How many **Contest Rounds** are there in between **Replacement Events** ?

- ○ It is randomly determined and there are always the same number of rounds in between **Replacement Events**
- ○ Always 4 rounds in between **Replacement Events**
- --> That is incorrect, please try again
- ◉ It is randomly determined and there is possibly a different number of rounds in between **Replacement Events**
- --> Correct! After each round there is a 90% probability of participating in a new round before a new Replacement Event

2. Are instructions going to be changing throughout the experiment?

- ◉ No, instructions stay the same throughout the experiment
- --> Correct! Instructions stay the same. A summary of the instructions is provided in the decision screens
- ○ Yes, new instructions will be provided every other **Replacement Event**
- ○ Yes, instructions change in the middle of the session

3. If I am the only participant who invests in a **Contest Round**:

- ○ I would take 75% of the prize.
- ◉ I would take a 100% of the prize.
- --> Correct! If you are the only participant investing you will certainly receive the whole prize
- ○ It depends on how much I invested.

4. What happens if I have the lowest round payoff and a **Replacement Event** occurs at the end of that round?

- ○ It will depend on my average payoff since the last **Replacement Event**
- ◉ I will be asked to leave the study because of my low round payoff
- --> Correct! Whenever a Replacement Event occurs, the participant with the lowest payoff in that round must leave
- ○ I will be able to keep playing for just one more round

5. What are the expected round payoffs if all my opponents and I decide to invest exactly *L$30* in a **Contest Round**:

- ○ We would each receive *L$50* of the prize and keep *L$70* of our respective endowments
- ○ We would each receive *L$70* and keep *L$25* of our respective endowments
- ◉ We would each receive *L$25* and keep *L$70* of our respective endowments
- --> Correct! Each participant would get a 25% of the prize, that is L$25 each

6.What percentage of the prize would you take if you and one other participant invest the same amount and everyone else invests zero?

- ◉ 50%
- --> Correct! The prize would be equally split between the 2 participants that invest the same positive amount
- ○ 25%
- ○ 100%

Next

A.8 Quiz screen 1, No Pressure Treatment

Instructions Quiz Part I

Before proceeding to the study, please answer the following questions regarding the instructions you just read:

1.How many **Contest Rounds** are there in between **Replacement Events** ?

- ○ It is randomly determined and there are always the same number of rounds in between **Replacement Events**
- ○ Always 4 rounds in between **Replacement Events**
- --> That is incorrect, please try again
- ◉ It is randomly determined and there is possibly a different number of rounds in between **Replacement Events**
- --> Correct! After each round there is a 90% probability of participating in a new round before a new Replacement Event

2. Are instructions going to be changing throughout the experiment?

- ◉ No, instructions stay the same throughout the experiment
- --> Correct! Instructions stay the same. A summary of the instructions is provided in the decision screens
- ○ Yes, new instructions will be provided every other **Replacement Event**
- ○ Yes, instructions change in the middle of the session

3. If I am the only participant who invests in a **Contest Round**:

- ○ I would take 75% of the prize.
- ◉ I would take a 100% of the prize.
- --> Correct! If you are the only participant investing you will certainly receive the whole prize
- ○ It depends on how much I invested.

4. What happens if I have the lowest round payoff and a **Replacement Event** occurs at the end of that round?

- ○ It will depend on my average payoff since the last **Replacement Event**
- ◉ One participant is randomly selected to leave regardless of payoffs
- --> Correct! Whenever a Replacement Event occurs one participant is randomly selected to leave regardless of payoffs
- ○ I will be able to keep playing for just one more round

5. What are the expected round payoffs if all my opponents and I decide to invest exactly *L$30* in a **Contest Round**:

- ○ We would each receive *L$50* of the prize and keep *L$70* of our respective endowments
- ○ We would each receive *L$70* and keep *L$25* of our respective endowments
- ◉ We would each receive *L$25* and keep *L$70* of our respective endowments
- --> Correct! Each participant would get a 25% of the prize, that is L$25 each

6.What percentage of the prize would you take if you and one other participant invest the same amount and everyone else invests zero?

- ◉ 50%
- --> Correct! The prize would be equally split between the 2 participants that invest the same positive amount
- ○ 25%
- ○ 100%

Next

A.9 Quiz screen 2, Pressure Treatment

Instructions Quiz Part II

Please use the sliders or input boxes (same interface you will use in each Contest Round) to answer the following questions regarding the instructions you just read:

Enter your **prediction for your opponents' average investment** in this round: ***L$*** 27

L$100

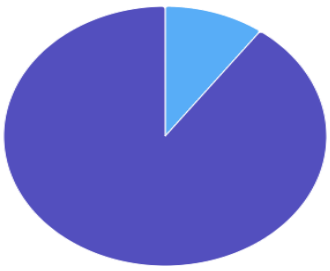
L$0

How much **would you like to invest** to increase your share of the prize: ***L$*** 9

L$100

L$0

Expected split of the prize:



REMEMBER:

You'll keep your endowment minus your investment and receive a fraction of the value of the prize, L$100, which depends on your and your opponents' investments.

If no ones invests, everyone keeps their endowment and the prize is split four ways.

Based on your prediction and investment, you expect to receive:

- **10.00% of the prize of L$100, that is L$10.00**
- **keep L$91.00 from your endowment**
  - **Thus, your expected payoff is L$101.00**
  - **And your opponents' average, L$103.00**

Questions:

7. If you expect your opponents to invest an average of *L$25* and you invest *L$55*, then what percentage of the prize would you expect to receive?

- 22.56% of the prize
- 82.25% of the prize
- (●) 42.31% of the prize

--> Correct! You are using the sliders properly

8. If you expect your opponents to invest an average of *L$25* and you invest *L$25*, then what is the payoff you would expect to receive?

- (●) *L$100*

--> Correct! Your payoff would be L$100: L$75 coming from your original endowment plus 25% of the prize

- *L$125*
- *L$75*

9. If you expect your opponents to invest an average of *L$10*, which of the following investment choice would result in the highest percentage of the prize for you?

- Invest *L$25*
- Invest *L$50*
- (●) Invest *L$100*

--> Correct! Invest L$100 if you only care about maximizing your share of the prize

10. If you expect your opponents to invest an average of *L$27*, which of the following investment choice would result in the highest payoff for you?

- (●) Invest *L$9*

--> Correct! This would maximize your payoff, which includes what you keep from your endowment

- Invest *L$25*
- Invest *L$60*

Next

A.10 Quiz screen 2, No Pressure Treatment

Instructions Quiz Part II

Please use the sliders or input boxes (same interface you will use in each Contest Round) to answer the following questions regarding the instructions you just read:

Enter your **prediction for your opponents' average investment** in this round: ***L$*** **27**

L$100

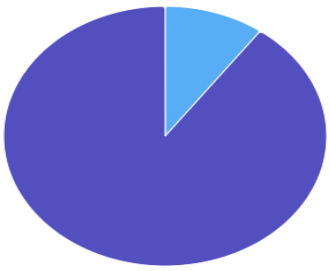
L$0

How much **would you like to invest** to increase your share of the prize: ***L$*** **9**

L$100

L$0

Expected split of the prize:



REMEMBER:

You'll keep your endowment minus your investment and receive a fraction of the value of the prize, L$100, which depends on your and your opponents' investments.

If no ones invests, everyone keeps their endowment and the prize is split four ways.

Based on your prediction and investment, you expect to receive:

- **10.00% of the prize of L$100, that is L$10.00**
- **keep L$91.00 from your endowment**
  - **Thus, your expected payoff is L$101.00**
  - **And your opponents' average, L$103.00**

Questions:

7. If you expect your opponents to invest an average of *L$25* and you invest *L$55*, then what percentage of the prize would you expect to receive?

- ○ 22.56% of the prize
- ○ 82.25% of the prize
- ◉ 42.31% of the prize

--> Correct! You are using the sliders properly

8. If you expect your opponents to invest an average of *L$25* and you invest *L$25*, then what is the payoff you would expect to receive?

- ◉ *L$100*

--> Correct! Your payoff would be L$100: L$75 coming from your original endowment plus 25% of the prize

- ○ *L$125*
- ○ *L$75*

9. If you expect your opponents to invest an average of *L$10*, which of the following investment choice would result in the highest percentage of the prize for you?

- ○ Invest *L$25*
- ○ Invest *L$50*
- ◉ Invest *L$100*

--> Correct! Invest L$100 if you only care about maximizing your share of the prize

10. If you expect your opponents to invest an average of *L$27*, which of the following investment choice would result in the highest payoff for you?

- ◉ Invest *L$9*

--> Correct! This would maximize your payoff, which includes what you keep from your endowment

- ○ Invest *L$25*
- ○ Invest *L$60*

Next

A.11 Post-Experiment Survey screen 1

Exit Questionnaire

The following questionnaire is for research purposes only. Your answers will stay anonymous. Your payment will be prepared while you answer this questionnaire. We thank you for your cooperation.

1. How old are you?

2. What is your sex?

○ Male ○ Female ○ Non-Binary

3. What is (closest) to your major field of study? If more than one major, or major not represented, please select "other STEM" or "non-STEM" as appropriate

----

4. Which one of the following best describes you?

----

5. What is your current GPA ?

6. Choose the scale that best describes how you see yourself: are you a person who is generally willing to take risks, or do you try to avoid taking risks?

Completely unwilling	○ 0	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Very willing

7. Choose the scale that best describes how willing are you to give up something that is beneficial for you today in order to benefit more from that in the future?

Completely unwilling	○ 0	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Very willing

8. Choose the scale to which the following statements describe you: "Competition brings the best out of me"

Not at all like me	○ 0	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Exactly like me

9. How many math classes have you taken in college?

10. How many statistics classes have you taken in college?"

11. How many economics classes have you taken in college?"

Next

Post-Experiment Survey screen 2 and 3

Exit Questionnaire

For the next four questions, please provide the answer that you think is better.

11. If John can drink one barrel of water in 6 days, and Mary can drink one barrel of water in 12 days, how many days would it take them to drink one barrel of water together?

12. Jerry received both the 15th highest and the 15th lowest mark in the class. How many students are in the class?

13. A man buys a pig for $60, sells it for $70, buys it back for $80, and sells it finally for $90. How much ($) has he made?

14. Simon decided to invest $8,000 in the stock market one day early in 2008. Six months after he invested, on July 17, the stocks he had purchased were down 50%. Fortunately for Simon, from July 17 to October 17, the stocks he had purchased went up 75%. At this point, Simon has:

- broke even in the stock market
- is ahead of where he began
- has lost money

Next

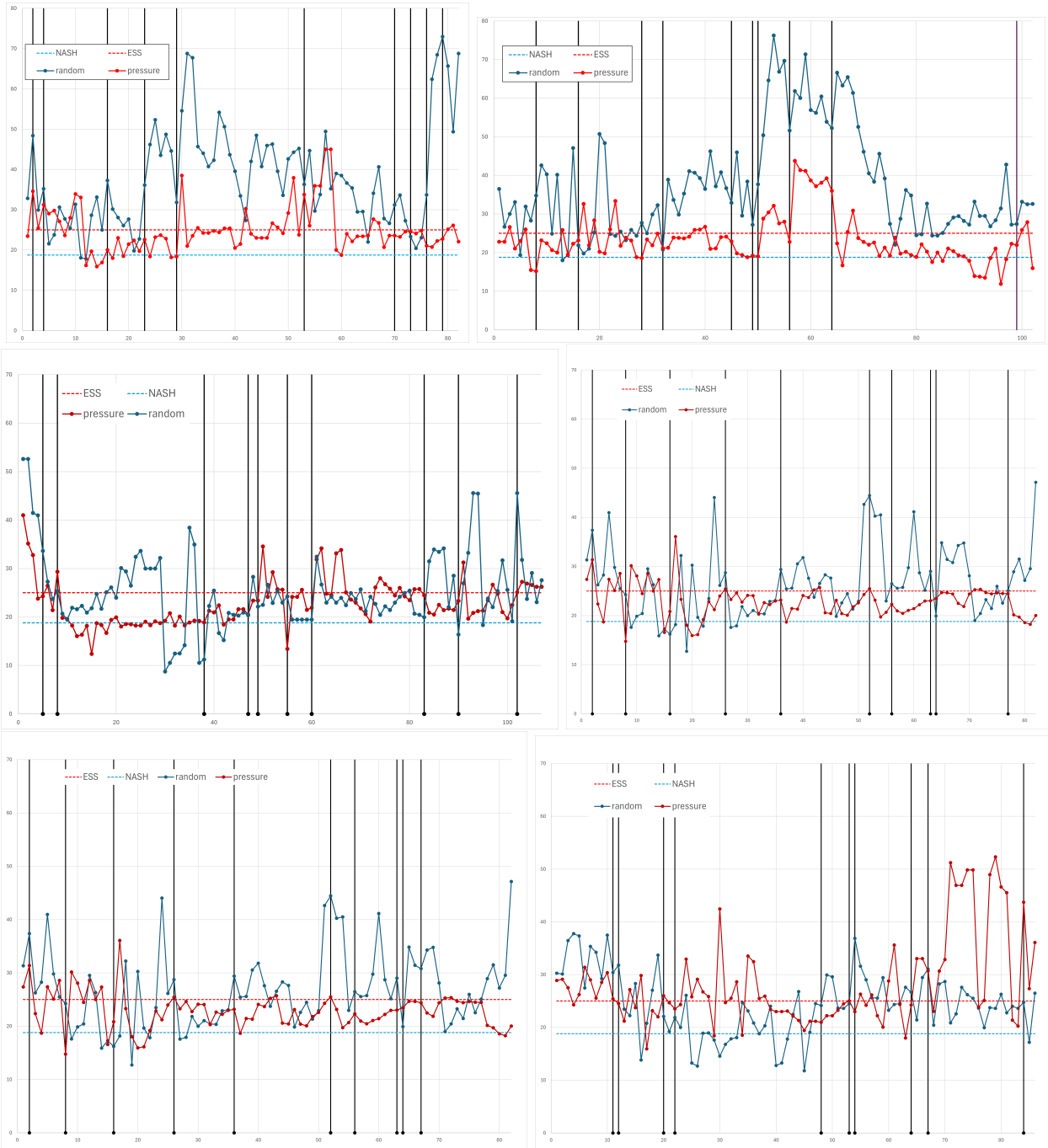
Exit Questionnaire

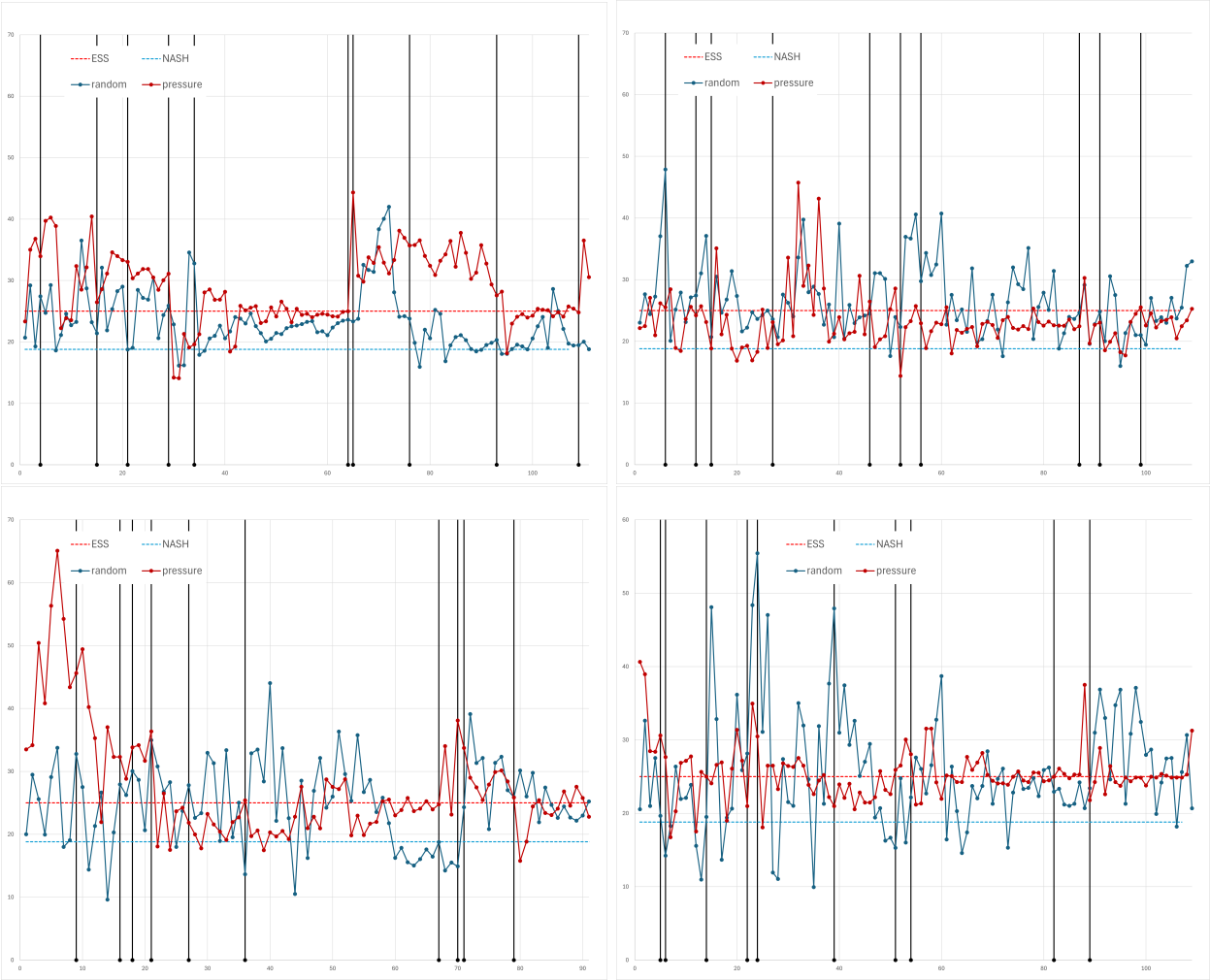
15. Please briefly describe your strategy/approach when deciding your investment.

Next

B Session-Level Investment Patterns

The Figures below display average Investment Patterns by session pair for the 10 sessions conducted of each treatment. Recall that pairs of sessions use the same allocations of replacement cycles. Most **Pressure**-sessions display lower levels and variance of investments. In **No-Pressure**-sessions, investment levels are highly volatile and rise significantly above both Nash- and ESS-levels.

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