Enhancing Effort Supply with Prize-Augmenting Entry Fees: Theory and Experiments*

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Abstract

Entry fees are widely observed in contests. We study the effect of a prize-augmenting entry fee on expected total effort in an all-pay auction setting where the contestants' abilities are private information. While an entry fee reduces equilibrium entry, it can enhance the entrants' effort supply. Our theoretical model demonstrates that the optimal entry fee is strictly positive and finite. We design a laboratory experiment to empirically test the effect of entry fees on effort supply. Our results provide strong support for the notion that a principal can elicit higher effort using an appropriately set entry fee to augment the prize purse.

Keywords: All-pay auction, Carrot and stick, Effort, Entry Fee, Prize allocation

JEL classification: C91, D44, J41, L23

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1 Introduction

Contests are observed in a wide range of environments such as labor markets, investments in research and development, political campaigns, advertising, lobbying, conflict, and sports, etc. In many situations, the goal of the contests is to elicit productive effort. For this purpose, the prize allocation rule has long been recognized as a major instrument that the contest organizer can use to enhance effort supply. In particular, the principle of "carrot and stick" has been long and widely followed in practice as a guideline for effective design to provide the right incentives to agents. In a contest setting, a positive prize can be viewed as a carrot, while a negative prize can be viewed as a stick. In this paper, we study a contest design problem—similar to Liu et al. (2018)—that allows both positive and negative prizes. The contest designer can use an entry fee as an instrument to create negative prizes for losers. Entry fees are added to the original prize purse, which will be awarded as a single winning prize to the contestant who exerts the highest effort. All losing participants win nothing but pay the entry fee, which represents a negative prize ex post.

Bundling the sum of the revenue collected from awarding negative prizes into the reward paid as a positive prize has a number of empirical analogs. Sporting contests often require monetary payments to enter the contest and these entry fees are used to partly fund the prize paid to the winner. Examples from sports include registration fees for marathons and "buy-ins" in poker tournaments, both of which are required entry fees in order to compete that are then used as part of the prize purse. Outside the realm of sports, contests in the creative industries often require prize-augmenting entry fees, including contests giving awards for best works of writing, photography, architecture, and design.[1]

We consider an all-pay auction with incomplete information, where the bidders' abilities are their private information. The bidders simultaneously decide whether to pay the entry fee to participate, and how to bid if they decide to enter without observing the others' entry and bidding decisions. The effect of an entry fee on effort supply is two-fold. On one hand, it discourages the

[1] Several contests explicitly mention that the entry fees are used to supplement the prize paid to the winner. Fredriksson (1993) discusses rodeos where the "entrance fees were added to the prize money." In horse racing, the Thoroughbred Owners and Breeders Association discusses races in which the "sum of owners' entry fees" are added to the prize purse (https://www.toba.org/owner-education/entering-races.aspx). Concerning design contests, http://www.victoriastrauss.com/advice/contests says that contests "charge a fee to fund the prize." Finally, in the context of writing contests, https://www.freelancer.sg/feesandcharges says that entry fees "will be used to increase the contest prize," while http://thewritelife.com/27-free-writing-contests/ says that entry fees are used as a "way of [growing] the prize purse for each contest."

low ability types from participating in the competition, which lowers their effort supply. On the other hand, entry fees increase the winner's prize, which induces more effort from higher types. The total effect thus relies on the trade-off between these two effects. Our theoretical study shows that imposing an entry fee indeed enhances the effort supply of agents if it is set appropriately. We establish that the effort-maximizing entry fee must be strictly positive and finite. This result helps to explain why entry fees are widely observed in practice.

We verify our theoretical predictions in a laboratory experiment. Our analysis focuses on the expected total effort of the contestants, which in our context is equivalent to the revenue raised by the contest designer. We experimentally vary the entry fee and the nature of contestant heterogeneity in a between-subject design. The entry fee is either set at zero, the optimal level, or higher than the optimal level. Contestant heterogeneity is not a treatment variable of our primary interest but is instead used to present a robust analysis of the optimal entry fee in different settings of interest. The degree of heterogeneity is measured by the variance of bidders' marginal cost distribution, where we vary the bounds of the uniform distribution.

Our experimental results strongly support the models' predictions. We find that revenue is the highest when the entry fee is set optimally and the prize is augmented with the total entry fees collected from the entrants. The revenue gains associated with the optimal entry fee is 26.75% more relative to no entry fee and 46.16% more relative to a high entry fee in these data. Further, we find strong support for two opposing effects that we demonstrate in our theoretical results. An entry fee creates a *discouragement effect* on weaker contestants. However, augmenting the prize with the sum of entry fees creates an *incentive effect* on stronger contestants. We indeed find that an entry fee discourages entry (the discouragement effect) but increases the bids of bidders who enter with a given marginal cost (the incentive effect). The optimal entry fee raises more revenue than no entry fee or a higher entry fee because it is successful at balancing these two effects.

The paper is organized as follows. Section 2 surveys the related literature. Section 3 presents our theoretical model and its predictions. We then describe our experimental design and procedures in Section 4 and discuss our experimental results in Section 5. Section 6 concludes.

2 Related Literature

Optimal prize allocation has been studied in various all-pay auction frameworks starting from the seminal work of Moldovanu and Sela (2001). They establish winner-take-all as the optimal prize allocation rule when contestants' effort function is linear or concave, while restricting prizes to be non-negative. They also establish that convex effort cost can invalidate the optimality of the winner-take-all. Minor (2013) maintains the assumption of non-negative prizes and studies the optimal prize allocation rule when contestants have convex costs of effort or the contest designer has concave benefit of effort. Moldovanu and Sela (2006) generalize their earlier investigation to a two-stage all-pay auction framework. Meanwhile, Moldovanu, Sela, and Shi (2007) analyze the environment where contestants care about their relative status. They further allow for negative prizes in Moldovanu, Sela, and Shi (2012). In Moldovanu, Sela, and Shi (2012), a negative prize is costly for the organizer to implement. In our paper, when negative prizes are implemented for some contestants, the revenue collected, like in Fullerton and McAfee (1999) and Liu et al. (2018), will be used by the organizer to reward other contestants.

Our paper is closely related to Liu et al. (2018) who adopt a mechanism design approach to study the effort-maximizing prize allocation rule allowing both positive and negative prizes. Imposing an endogenous effort threshold, Liu et al. (2018) characterize the optimal prize allocation rule and show that such an allocation rule is optimal in a general class of contest mechanisms. In Liu et al. (2018), a contestant, if he bids, must bid above a threshold. If no one bids, all bidders equally share the total prize budget, which makes all bidders participate at the optimum in their setting. The issue of endogenous entry, absent in their paper, however, definitely arises here in our environment, since only the highest bidder gets a single positive prize but all pay an entry fee. This issue would potentially reduce the effort supply and complicate the trade-off. Nevertheless, we find that, at the optimum, entry fee—a special form of negative prize—still prevails, as the optimal entry fee is always positive.

Thomas and Wang (2013) present a model in which the highest bidding contestant wins a fixed prize (V) and the lowest bidding contestant pays a fine (P), with $P < V$. The contest designer sets the optimal level of fine P. Contestants must decide whether to participate in the contest. If there is only one bidder who participates in the contest, she will win the prize, but she also must pay the fine because her bid is both the highest and the lowest. Different from theirs, in our setup, all contestants must pay an entry fee, regardless of whether their bid is the lowest bid. The revenues collected from entry fees are then added onto the winning prize. Further, in our setup, contestants are heterogeneous in their marginal bidding costs. We know from the literature that greater cost heterogeneity discourages weaker contestants from competing (Schotter and Weigelt, 1992; Gradstein, 1995; Clark and Riis, 1998). This *discouragement effect* may reduce effort.[2] Counter to this negative effect, Moldovanu and Sela (2001) show that having multiple prizes encourages weaker contestants to participate. However, this also comes at a cost of inducing stronger contestants to lower their effort. Moldovanu and Sela (2001) show that, only when bidding costs are sufficiently convex, awarding multiple prizes may be optimal.[3]

Note that the entry fee in our setup essentially works as an endogenous participation constraint. Instead of using entry fee to create the participation constraint, Megidish and Sela (2013) use the minimal effort constraint in which a contestant is only allowed to participate if her effort exceeds the minimal effort constraint. The minimal effort constraint works in a similar fashion as the entry fee in our setup. Further, Megidish and Sela (2013) consider two alternative prize allocation schemes. The first one is the winner-take-all scheme and the second one is the random allocation scheme. With the random allocation scheme, all contestants who exert efforts that exceed the minimal effort constraint has an equal chance to win the prize. They show that the random prize allocation scheme induces greater participation from contestants. The increase in the number of participants could offset the reduction in effort due to the discouragement effect. They show that the random prize allocation scheme is potentially superior to the winner-take-all allocation scheme.

In our paper, we design a lab experiment to test the predictions of our prize-augmenting entry fee scheme on the total expected effort. The question is whether this scheme creates a strong enough incentive for stronger contestants to exert high effort, such that it outweighs the loss from weaker contestants who are less likely to enter the contest because of an entry fee. To the best of our knowledge, our paper is the first to present an experimental analysis of an all-pay auction

[2] Llorente-Saguer, Sheremeta, and Szech (2016) study the discouragement effect directly and ask whether contests can be designed in ways that ameliorated it. Their results confirm that the contest designer can reduce the discouragement effect by favoring weaker contestants (e.g., bid-caps and favorable tie-breaking rules) but they find mixed evidence on whether these designs can increase revenue.

[3] Several experimental papers have found that a single prize generates higher effort than multiple prizes (Vandegrift, Yavas, and Brown, 2007; Sheremeta, 2011; Stracke, Höchtl, Kerschbamer, and Sunde, 2014; Cason, Masters, and Sheremeta, 2010).

with prize-augmenting entry fee mechanism. While Dechenaux, Kovenock, and Sheremeta (2014) comprehensively survey contest experiments, we discuss several of the most related experimental papers. Davis and Reilly (1998) study an all-pay first-price sealed-bid auction, in addition to several other contest formats, to understand the role of institutional arrangements on rent-seeking. They find that more rents are dissipated in auctions than in lotteries. Closer to our focus on revenue maximization, Barut, Kovenock, and Noussair (2002) show that all-pay and winner-pay auctions generate revenues that cannot be empirically distinguished. In contrast, Noussair and Silver (2006) find that all-pay auctions earn more revenue than winner-pay auctions. Both of these papers find that all-pay auctions generate more revenue in the data than is predicted under risk neutrality.

Two experimental papers that are closely related to ours are Anderson and Stafford (2003) and Müller and Schotter (2010). Anderson and Stafford (2003) study contestants who have differing cost of effort and must pay an entry fee to participate in the contest. Their results show that higher cost heterogeneity reduces the number of entrants and effort. Müller and Schotter (2010) find that, while theory predicts a continuous mapping between ability and effort, effort functions in the data bifurcate (i.e., low types drop out or provide little effort and high types overexert effort).

3 Theoretical Model with Incomplete Information

We consider an all-pay auction in which the player with the highest effort wins a single prize. There are N (≥ 2) potential bidders whose marginal bidding costs are their private information. Every bidder i's marginal bidding cost c_i is identically and independently distributed on interval $[\underline{c}, \overline{c}]$ with a cumulative distribution function $F(\cdot)$ and a density function $f(\cdot) > 0$ over the support $[\underline{c}, \overline{c}]$, where $\underline{c} > 0$. Type $\underline{c}$ is thus the most efficient type.

The auction has an initial fixed prize V and the organizer can set an entry fee E that is collected from entrants to augment the initial prize. Therefore, when there are n entrants, then the total prize will be $V_n(E) = V + nE$, $n = 0, 1, 2, ..., N$. Entrants make their bid simultaneously without observing the number of actual bidders. The highest bid among n (≥ 1) entrants then wins the single prize $V_n(E)$. If there is no entrant, the organizer keeps the initial prize.

A positive entry fee E induces endogenous symmetric entry, which can be denoted by an entry threshold $\hat{c} \in [\underline{c}, \overline{c}]$. Only the more efficient types with $c_i \leq \hat{c}$ would pay the entry fee and participate in the contest. Given monotonicity of the entrants' symmetric bidding strategy, an entrant with the threshold type (i.e., type $\hat{c}$) wins if and only if she is the only entrant. In this case, she wins $V_1(E) = V + E$ with probability $[1 - F(\hat{c})]^{N-1}$, and must pay the entry fee E. In addition, his equilibrium bid must be $b(\hat{c}) = 0$ in an all-pay auction. Therefore, we must have

$$[1 - F(\hat{c})]^{N-1}[V + E] = E,$$

which leads to the following lemma.

Lemma 1. *With entry fee E, the symmetric entry threshold is*

$$\hat{c} = F^{-1}[1 - (\frac{E}{V+E})^{\frac{1}{N-1}}] \in (\underline{c}, \overline{c}], \forall E \geq 0.$$

Note that $\hat{c}$ decreases with E. In particular, when $E = 0$, we have $\hat{c} = \overline{c}$, i.e., every type participates.

We next derive the monotone equilibrium bidding strategy $b(c), \forall c \leq \hat{c}$. Consider a representative bidder, say bidder 1. Suppose the other bidders $i = 2, 3, ..., N$ adopt the equilibrium entry threshold $\hat{c}$, and hypothetical bidding strategy $b(c)$. If bidder 1 enters and announces a type $c' \leq \hat{c}$ when his true type is $c \leq \hat{c}$, then his expected payoff is

$$\begin{aligned} \pi_1(c', c) &= \sum_{n=0}^{N-1} C_{N-1}^n F(\hat{c})^n [1 - F(\hat{c})]^{(N-1)-n} [1 - \frac{F(c')}{F(\hat{c})}]^n V_{n+1}(E) - b(c')c - E \\ &= \sum_{n=0}^{N-1} C_{N-1}^n [1 - F(\hat{c})]^{(N-1)-n} [F(\hat{c}) - F(c')]^n V_{n+1}(E) - b(c')c - E. \end{aligned}$$

Together with the first-order condition for optimal bid, truth-telling (i.e., $c' = c$ at the optimum) in equilibrium implies

$$\frac{\partial \pi_1(c', c)}{\partial c'}|_{c'=c} = -f(c) \sum_{n=1}^{N-1} C_{N-1}^n [1 - F(\hat{c})]^{(N-1)-n} n [F(\hat{c}) - F(c)]^{n-1} V_{n+1}(E) - b'(c)c = 0.$$

We thus have

$$b'(c) = -\frac{f(c)}{c} \sum_{n=1}^{N-1} C_{N-1}^n [1 - F(\hat{c})]^{(N-1)-n} n [F(\hat{c}) - F(c)]^{n-1} V_{n+1}(E),$$

with boundary condition $b(\hat{c}) = 0$. We thus obtain the solution of $b(c)$, as shown in the following proposition.

Proposition 1. *With entry fee E, the symmetric bidding strategy of entrants is*

$$b(c; E) = \int_{c}^{\hat{c}(E)} \frac{f(t)}{t} \sum_{n=1}^{N-1} C_{N-1}^{n} [1 - F(\hat{c}(E))]^{(N-1)-n} n [F(\hat{c}(E)) - F(t)]^{n-1} V_{n+1}(E) dt, \ \forall c \leq \hat{c}(E),$$

where $\hat{c}(E) = F^{-1}[1 - (\frac{E}{V+E})^{\frac{1}{N-1}}]$.

Using the entry equilibrium in Lemma 1 and bidding equilibrium in Proposition 1, we can derive the equilibrium expected total effort as follows.

Corollary 1. *With entry fee E, the equilibrium expected total effort is*

$$TE(E) = N \int_{\underline{c}}^{\hat{c}(E)} \frac{f(t)}{t} \sum_{n=1}^{N-1} C_{N-1}^{n} [1 - F(\hat{c}(E))]^{(N-1)-n} n [F(\hat{c}(E)) - F(t)]^{n-1} V_{n+1}(E) F(t) dt,$$

where $\hat{c}(E) = F^{-1}[1 - (\frac{E}{V+E})^{\frac{1}{N-1}}]$.

Proof. See Appendix A. □

The focus of this paper is how a prize-augmenting entry fee can enhance effort supply in an all-pay auction. With the above results, we are ready to carry out this analysis.

Proposition 2. *The optimal entry fee must be positive.*

Proof. See Appendix A. □

The following proposition further shows that the optimal level of an entry fee is finite.

Proposition 3. *The optimal entry fee must be finite.*

Proof. See Appendix A. □

It is standard from auction theory that, when the virtual value function is monotone, the revenue-maximizing entry fee is positive if and only if the virtual value of the lowest valuation type is positive. The contest rule studied here is an all-pay auction; therefore, one may expect that some similar condition on the CDF $F(\cdot)$ is needed to guarantee an optimal entry fee to be positive.

However, notice that Proposition 2 does not rely on such an assumption; the only assumption we make on $F(\cdot)$ is that its density is strictly positive. The key reason for such a difference between auctions and contests is that, entry fee in auctions serves as a screening device (collecting some revenue at the same time) which would not distort players' bidding incentive, while entry fee in contests would be topped up to the grand prize to strengthen players' bidding incentive (as illustrated in Figure 1) in addition to serving as a screening device.

More specifically, the seller in a revenue-generating auction keeps the entry fees collected as part of the revenue and the entry fee serves only as an instrument to control entry. Further, the well-known revenue equivalence theorem says that two mechanisms generate the same expected revenue given that they implement the same allocation and that the lowest type earns the same expected payoff. According to the revenue equivalence theorem, if the minimum winning type (i.e., the lowest type that wins the auction with positive probability) is higher than the lower bound of the value distribution, then a continuum of pairs of reserve price and entry fee would generate the same expected revenue in an all-pay auction. In particular, there is an optimal entry fee that would maximize revenue if there is no reserve price. However, zero entry fee is optimal if the lowest winning type equals the lower bound of bidders' values regardless of the reserve price. In contests, entry fees augment the prize purse to induce more effort from the entrants of different types, in addition to controlling entry. It is thus less clear that a prize-augmenting entry fee would induce higher effort given that it discourages entry, especially for a type distribution that must entail zero optimal entry fee in a revenue-generating auction. Nevertheless, Proposition 2 unambiguously establishes theoretically that, regardless of the type distribution, a non-zero entry fee must be optimal in an effort-eliciting all-pay contest with incomplete information.

Having established the general results, we use $N = 2$ to illustrate the effect of the entry fee on the bidding function and the expected total effort elicited. Assume that the marginal cost of exerting effort c_i follows the uniform distribution with support $[1, 2]$, so that $F(t) = t - 1$ and $f(t) = 1$, $t \in [1, 2]$. For simplicity, let $V = 1$. Then according to Proposition 1, the bidding function is

$$b(c; E) = (1 + 2E) \int_c^{\hat{c}(E)} \frac{1}{t} dt = (1 + 2E)(\ln \hat{c}(E) - \ln c),\ \forall c \leq \hat{c}(E),$$

where

$$\hat{c}(E) = \frac{2+E}{1+E}.$$

Further, by Corollary 1, the expected total effort is

$$\begin{aligned} TE(E) &= 2(1+2E)\int_1^{\hat{c}(E)} \frac{t-1}{t}dt \\ &= 2(1+2E)(\hat{c}(E) - 1 - \ln \hat{c}(E)) \\ &= 2(1+2E)(\frac{1}{1+E} - \ln \frac{2+E}{1+E}). \end{aligned}$$

Notice that

$$\frac{\partial}{\partial E}(\frac{\partial b(c;E)}{\partial c}) = -\frac{2}{c},$$

which implies that the absolute value of the slope of the bidding function is increasing in the level of the entry fee given that $c \leq \hat{c}(E)$. This leads to the central trade-off of introducing entry fee: on the one hand, the introduction of an entry fee enlarges the grand prize awarded to the most able entrant, so that the entrant bids more aggressively when entry fee becomes larger; on the other hand, a higher entry fee dampens the entry incentive of the high cost contestants, so that *ex ante* the expected number of entrants is smaller. Since the expected total effort depends on both the bidding behavior and the entry incentive, these two conflicting effects are the trade-off the organizer faces. According to Propositions 2 and 3, when the entry fee is small enough, the former effect dominates the latter one; while when the entry fee is large enough, the latter effect dominates. The goal is to balance these two effects.

Figure 1 illustrates how the bidding functions vary with the magnitude of the entry fee, for $E = 0$, 0.5, and 1, respectively.

The absolute value of the slope of the bidding function is increasing in the magnitude of the entry fee. Though a higher entry fee induces more aggressive bidding from the entrants with lower marginal costs, it also discourages entry.

Figure 2 further illustrates how the total effort elicited varies with the level of the entry fee. As can be seen from Figure 2, the total effort first rises when entry fee increases, and then it descends when the entry fee further increases. In this case, the optimal entry fee is $E^* \approx 0.242$.

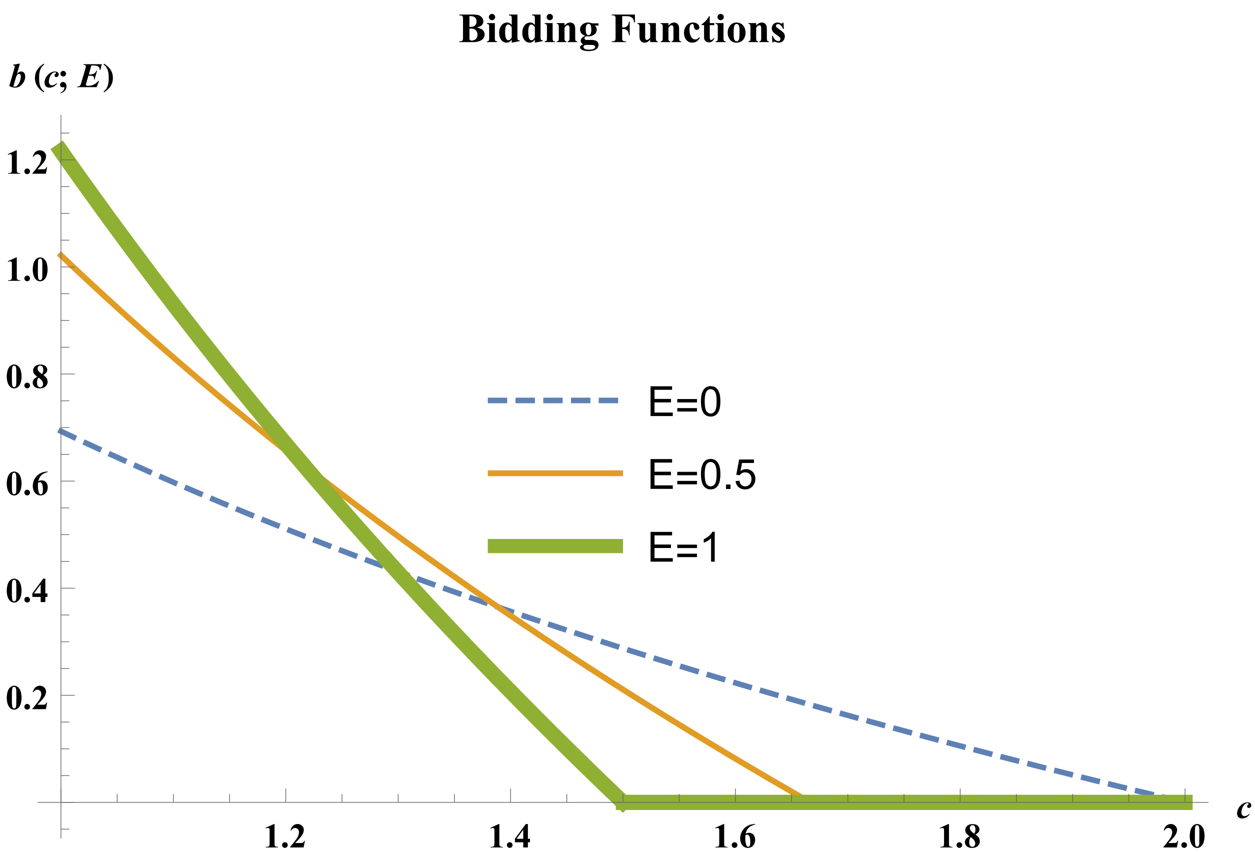

Figure 1: Bidding Functions as a Function of the Entry Fee

4 Experimental Design

In this section, we outline our experimental design and procedure aimed at testing the theoretical prediction, while keeping the experiment sufficiently tractable for experiment participants to follow. The experiment has $N = 2$ potential contestants and a prize valued at $V = 100$.[4] The marginal cost distribution of the contestants is drawn from a uniform distribution with cost bounds $[\underline{c}, \overline{c}] = [0.5, 1.5]$.[5] A contestant's marginal cost is her private information. Our treatment variation is the level of the entry fee E. In the baseline treatment, the optimal entry fee is $E = E^*$, which is the level that maximizes total effort. We compare this baseline treatment to treatments with no entry fee ($E = 0$) or a high entry fee ($E = 3E^*$). Relative to $E = E^*$, both $E = 0$ and $E = 3E^*$ should

[4] Theoretically, a positive and finite entry fee is optimal for any number of contestants, though the entry fee itself changes as the number of contestants changes. Because varying the number of contestants increases the scale of the experiment, we do not use the number of contestants as a treatment variable.

[5] The specific parameters for the bounds of the cost distribution were chosen to maximize the difference in the total effort as the level of the entry fee varied. This addresses the "flat maximum" critique of Harrison (1989) and ensures sufficient power of our statistical comparisons.

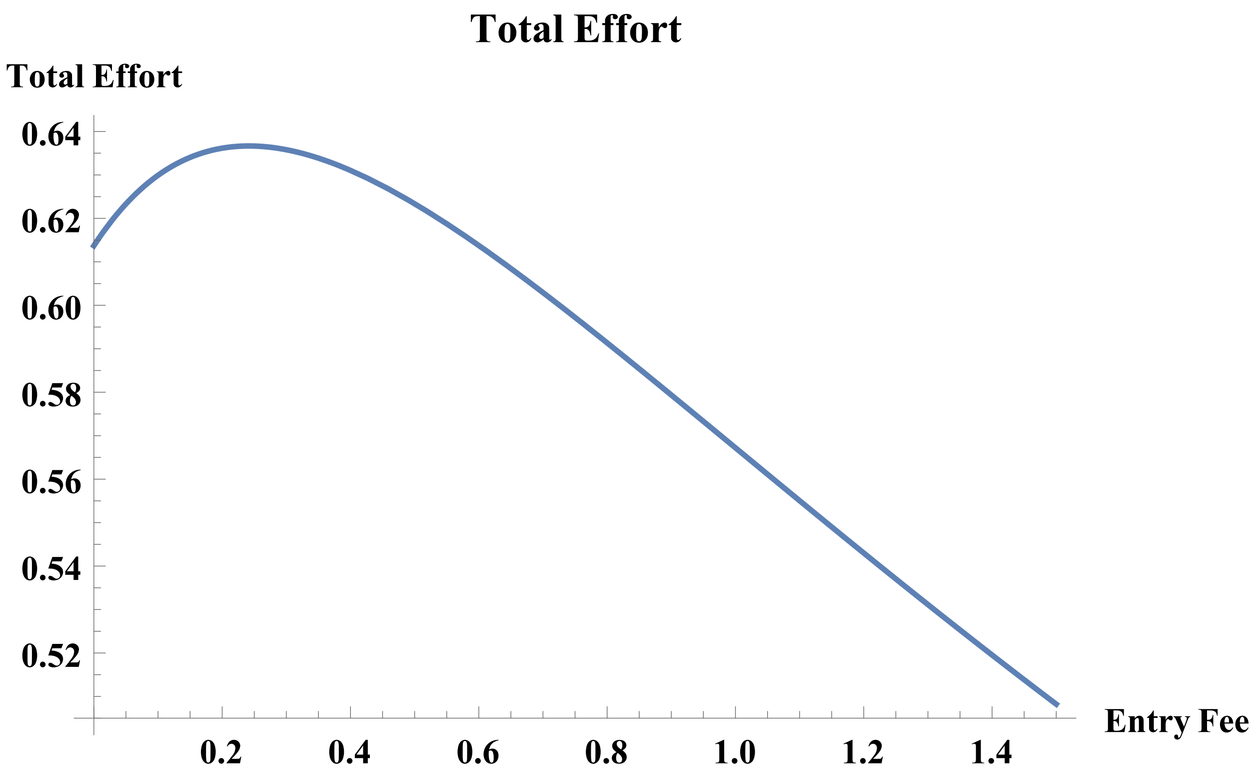

Figure 2: Total Effort as a Function of the Entry Fee

generate less total effort. By setting the high entry fee equal to three times the optimal level, we test whether any advantage of an entry fee is coming from setting it appropriately, rather than a spurious treatment effect from an entry fee that is arbitrarily set.

Using the results above, we calculate the entry threshold above which no contestant is predicted to enter ($\widehat{c}$), the equilibrium bidding function ($b(c;\widehat{c})$), and the optimal entry fee (E^*) that maximizes total effort.

$$\widehat{c} = \frac{300+E}{200+2E},$$
$$b(c;\widehat{c}) = (100+2E)\left[\ln\left(\frac{300+E}{200+2E}\right) - \ln c\right],\ \forall c \leq \widehat{c}_{1.5},$$
$$E^* = 40.393.$$

In total, we use a 3x1 design, as shown in Table 1. The table also shows the number of session per treatment, entry fee (E), entry threshold ($\widehat{c}$), and predicted total effort (TE).

We used a between-subject experimental design (i.e., each subject participated in only one cell

Table 1: Summary of Main Experimental Treatments

Zero Entry Fee ($E = 0$)	Optimal Entry Fee ($E = E^*$)	High Entry Fee ($E = 3E^*$)
5 Sessions	5 Sessions	5 Sessions
$E = 0$	$E = 40.3925$	$E = 121.1774$
$\widehat{c} = 1.5$	$\widehat{c} = 1.2123$	$\widehat{c} = 0.9521$
$TE = 90.1388$	$TE = 97.4287$	$TE = 89.0679$

Notes: The design of each treatment is shown, along with the number of sessions. In each cell, we provide the magnitude of the entry fee (E), the theoretical prediction for the entry threshold ($\widehat{c}$), and the theoretical prediction for the total effort (TE).

in Table 1). Based on our theoretical model, we should expect that there will be full entry into the contest with no entry fee ($E = 0$). However, in the presence of an entry fee, only contestants with the marginal cost lower than the entry threshold would enter. The contest designer's goal is to maximize the contest revenue and in our context, maximizing the contest revenue is equivalent to maximizing the expected total effort (TE) exerted by the contestants.

We also ran additional experimental sessions. These sessions serve as robustness checks and used different bounds of the marginal cost of the contestants. Wider bounds in the cost distribution reflect the degree of heterogeneity of the contestants. These additional sessions used two different cost distributions: $[\underline{c}, \overline{c}] = [1, 2]$ and $[\underline{c}, \overline{c}] = [1, 3]$. By using three different environments to characterize the heterogeneity among contestants, we can demonstrate the robustness of our empirical results. See Appendix D for full details.

4.1 The Experimental Procedure

Our subjects were recruited from the population of undergraduate students at Nanyang Technological University (NTU) in Singapore. They came from various majors such as science, engineering, business, economics, arts and humanities, and social sciences. The recruitment information was distributed through the university-level mass email system. The experiment had 360 subjects (24 subjects per session times 15 sessions). No subjects participated in more than one session.

At the beginning of each session, the subjects were given a random six digit numerical user ID as their identifier throughout the experiment. The subjects were randomly rematched in every period. They went through 30 periods of interactions conducted using the computer interface, which was programmed using z-Tree (Fischbacher, 2007). Subjects were not told in advance the total number of periods they would have to go through to minimize the end-game effect. The duration of the experiment was approximately 90 minutes. At the beginning of the experiment, written instructions were distributed to the subjects and were read aloud by the experimenter to ensure that the subjects had common knowledge about the experiment.[6] Subsequently, the subjects were given 2 trial periods to gain familiarity with the experimental interface and to ensure that they understood the experimental instructions. They were told that the payoff from these trial periods would be excluded from the determination of their final earnings.

At the end of the experiment, 5 periods were randomly selected out of 30 periods and their final earnings were the sum of the payoffs they earned in these 5 periods. The payoffs were denominated in experimental currency units (ECUs) and this information is clearly explained in the experimental instructions. To cover the bidding cost, the subjects were provided with a checkbook of 200 ECU at the beginning of every period. Each subject's payoff from a period will be her wining prize obtained is she wins the contest and her checkbook amount in that period minus the bidding cost incurred (inclusive of the entry fee). The exchange rate was S$ 1 for every 60 ECU.

After the contest game had been completed, the subjects answered a risk-elicitation survey using the multiple price list procedure of Holt and Laury (2002). On average the subjects earned between 20 ECU to 30 ECU from the Holt-Laury procedure. Subsequently, subjects were given 10 quantitative questions to measure their quantitative aptitude. They earned 5 ECU for every correct answer and 0 ECU for every wrong (or blank) answer. On average the subjects earned 25 ECU from this part. Following the quantitative questions, subjects provided information about their demographic and academic characteristics. The conversion rate for the Holt-Laury elicitation and the quantitative task was S$ 1 for every 10 ECU.

The subjects were also given a show-up fee of S$ 2. However, when the total earnings of a subject was less than S$ 8 (around US$ 6), we gave the subject an additional S$ 2 lump-sum fee at the end of the experiment. We did not, however, tell subjects about this at the beginning of the experiment to avoid any perverse incentive effect. This additional show-up fee was given so as not to discourage these low-earning subjects from participating in future experiments at the lab. However, there were only very few such cases where a subject earned less than S$ 8. After considering all

[6] The complete experimental instructions are available in Appendix B.

payment components, the average total earnings per subject was around S$ 23 (around US$ 17).[7]

5 Results from the Lab

Our main concern is the revenue raised by the principal. As the contest structure augments the prize purse with the entry fees paid by entrants, revenue is equal to the sum of all bids entered. The analysis first considers aggregate results at the treatment level, then moves to results at the level of an individual subject.

5.1 Aggregate Results

The first column of Table 2 shows the total effort expended by both contestants, which is equivalent to the revenue earned by the principal in each treatment.

Table 2: Summary Statistics for Total Effort, Bids, and Efficiency

	(1) Total Effort	(2) Bid if Enter	(3) Efficiency
Zero Entry Fee	110.669	61.068	0.654
	(1.806)	(0.914)	(0.011)
Optimal Entry Fee	140.273	94.495	0.658
	(2.231)	(1.141)	(0.011)
High Entry Fee	95.970	79.864	0.707
	(1.647)	(0.835)	(0.011)
N	5400	8097	5400

Notes: Column (1) provides the treatment-level means for the revenue raised in the contest, that is, the total effort. Column (2) provides the treatment-level means for bids of entering bidders. Column (3) provides the treatment-level means for the rate of efficiency of the contest, where a contest is efficient if the contestant with the lowest marginal cost wins. For this and subsequent tables, standard errors are shown in parentheses.

These treatment-level means are shown for each level of the entry fee. On average, the optimal entry fee induces more total effort than either no entry fee or an entry fee that is three times larger than the optimal entry fee. The advantage of the optimal entry fee in percentage terms is 26.75% more total effort with respect to no entry fee and 46.16% more total effort with respect to a high entry fee.[8] These large gains in total effort strongly support our theoretical predictions. The

[7] The payment for 1 hour part-time job in Singapore is around S$ 8.

[8] The comparison to a high entry fee was designed to test whether any advantages of an entry fee are indeed coming

remaining columns in Table 2 and the columns in Table 3 provide additional statistics of interest. Before discussing them, we provide additional analysis of our key outcome of interest, total effort.

Table 4 shows the average total effort in each session. In all 30 periods (Panel A), total effort is higher in each session with the optimal entry fee than in any session with zero entry fee. Given that we expect (and find) substantial overbidding that is ameliorated but not eliminated by learning, we also repeat the analysis for the final 10 periods out of a total of 30 periods in Panel B. In terms of total effort, the optimality of the optimal entry fee continues to hold in the final 10 periods.

Table 3: Summary Statistics for Entry

	(1) Number of Entrants	(2) Excess Entrants	(3) Entry Rate: High Types	(4) Entry Rate: Low Types
Zero Entry Fee	1.812	-0.188	0.906	
	(0.010)	(0.010)	(0.005)	
Optimal Entry Fee	1.484	0.054	0.823	0.534
	(0.014)	(0.017)	(0.009)	(0.021)
High Entry Fee	1.202	0.314	0.894	0.363
	(0.017)	(0.016)	(0.010)	(0.013)
N	5400	5400	3921	1479

Notes: Column (1) provides the treatment-level means for the the number of contestants who entered, out of two. Column (2) provides the treatment-level means for the number of excess entrants above the theoretically predicted number of entrants. Column (3) provides the treatment-level means for the probability of entry for the high types who are predicted to enter. Column (4) provides the treatment-level means for the probability of entry for the low types who are not predicted to enter.

With five sessions per treatment, we can test the difference in total effort between treatments, treating each session as a single data point. This conservative test allows us to address the possibility of session effects (Fréchette, 2012). The zero, optimal, and high entry fee groups exert 110.67, 140.27, and 95.97 points in total effort on average, respectively.[9] Our pairwise statistical comparisons have ten observations, one for each session. Relative to zero entry fee, the increase in total effort associated with the optimal entry fee has a difference (29.60 points) that is large and statistically significant (z-statistic = 2.61, p-value = 0.01). Relative to a high entry fee, the opti-

from setting it appropriately, rather than a spurious treatment effect from an entry fee that is arbitrarily set. Our results confirm that an entry fee can raise more revenue but only when it is set such that it balances the incentive and discouragement effects.

[9] We report means and standard errors for ease of comparison but the statistics tests that we will report are nonparametric.

mal entry fee extracts a lot more effort (44.30 points) and the difference is statistically significant (z-statistic = 2.61, p-value = 0.01). When considering only the final 10 periods, the magnitudes are only slightly reduced (25.21 and 40.68 points relative to zero and high, respectively) and the statistical significance is similar (z-statistic = 2.19, p-value = 0.03; z-statistic = 2.61, p-value = 0.01; relative to zero and high, respectively).

Table 4: Total Effort by Session

Panel A: *All 30 Periods*					
	Session 1	Session 2	Session 6	Session 13	Session 15
Zero Entry Fee	108.139 (3.932)	109.453 (4.330)	110.833 (4.011)	129.217 (4.085)	95.7018 (3.629)
	Session 3	Session 4	Session 5	Session 12	Session 14
Optimal Entry Fee	141.056 (4.825)	135.818 (5.495)	131.28 (4.809)	156.453 (4.761)	136.759 (4.944)
	Session 7	Session 8	Session 9	Session 10	Session 11
High Entry Fee	102.492 (3.741)	91.612 (3.352)	89.505 (3.824)	105.079 (3.640)	91.161 (3.775)
Panel B: *Final 10 Periods*					
	Session 1	Session 2	Session 6	Session 13	Session 15
Zero Entry Fee	116.488 (7.663)	88.448 (7.107)	102.738 (6.923)	124.106 (6.907)	85.049 (5.595)
	Session 3	Session 4	Session 5	Session 12	Session 14
Optimal Entry Fee	117.481 (6.610)	129.426 (10.107)	119.184 (8.188)	151.969 (8.554)	124.822 (8.609)
	Session 7	Session 8	Session 9	Session 10	Session 11
High Entry Fee	96.605 (6.390)	81.469 (5.855)	87.068 (6.877)	86.956 (6.299)	87.405 (7.146)

Notes: Total effort by session is shown. Panel A includes all periods, while Panel B includes only the final 10 periods.

Between-session comparisons allow us to remain conservative with respect to session effects, but they ignore most of the variation in the data. To complement this analysis, we present the total effort distributions between treatments. Figures 3 and 4 present empirical CDFs of total effort as the entry fee varies, for all periods (Figure 3) and for the final 10 periods only (Figure 4). The empirical CDF plots show that effort under the optimal entry fee first order stochastically dominates effort under high entry fee. Further, Figures 5 and 6 plot the these same empirical CDFs along with the corresponding theoretical CDF for all periods (Figure 5) and for the final 10 periods only (Figure 6). The theoretical CDF is constructed using the optimal bidding function (shown in Section 4), evaluated at the marginal cost draws of each bidder, in each group, in each period.

With no entry fee and the optimal entry fee, the empirical and theoretical CDFs are visibly different in that some contests generated more effort than predicted. This could occur from over-entry (with a positive entry fee) or overbidding; the next section analyzes individual behavior to study each dimension separately. The shift toward higher revenue in the empirical CDFs is stronger with the optimal entry fee than no entry fee. With a high entry fee, there are some contests that are predicted to generate a low level of total effort but empirically generate more total effort. In contrast, as the predicted level of total effort increases, the empirical CDF matches the theoretical CDF closely with a high entry fee.

Next, Figures 7 and 8 illustrate the corresponding average bid amounts of active bidders across the entire range of marginal bidding costs, for all periods (Figure 7) and for the final 10 periods only (Figure 8). These figures essentially depict the bidding functions derived from our experimental data. They are remarkably consistent with the theoretical bidding functions shown in Figure 1. First, a larger entry fee results in a steeper bidding function. Thus, the optimal entry fee results in higher bids, for a given cost, from active bidders relative to no entry fee; this is the incentive effect identified earlier. Second, with a positive entry fee, there exists a threshold marginal cost above which bidders do not enter. Thus, the optimal entry fee results in more bidders staying out from the contest; this is the aforementioned discouragement effect.

Beyond this analysis of total effort, we discuss additional outcomes of interest. Returning to Table 2, Column (2) shows bid amounts conditional on entering the contest. Bids of entering bidders are always higher on average with the optimal entry fee than bids with either no entry fee or a high entry fee. The differences are statistically significant (z-statistic = 3.72, p-value = 0.00; z-statistic = 12.23, p-value = 0.00; relative to zero and high, respectively). Note however that theory predicts (and we find) steeper bidding functions with a higher entry fee. As a result, bids conditional on entry only tells part of the story; this is why we focused on total effort above. Column (3) of Table 2 shows the treatment-level mean efficiency rate of the contests, where a contest is efficient if the contestant with the lowest marginal cost wins. Efficiency is similar with the optimal and no entry fee (z-statistic = 0.21, p-value = 0.83), but efficiency is higher with a high entry fee than with

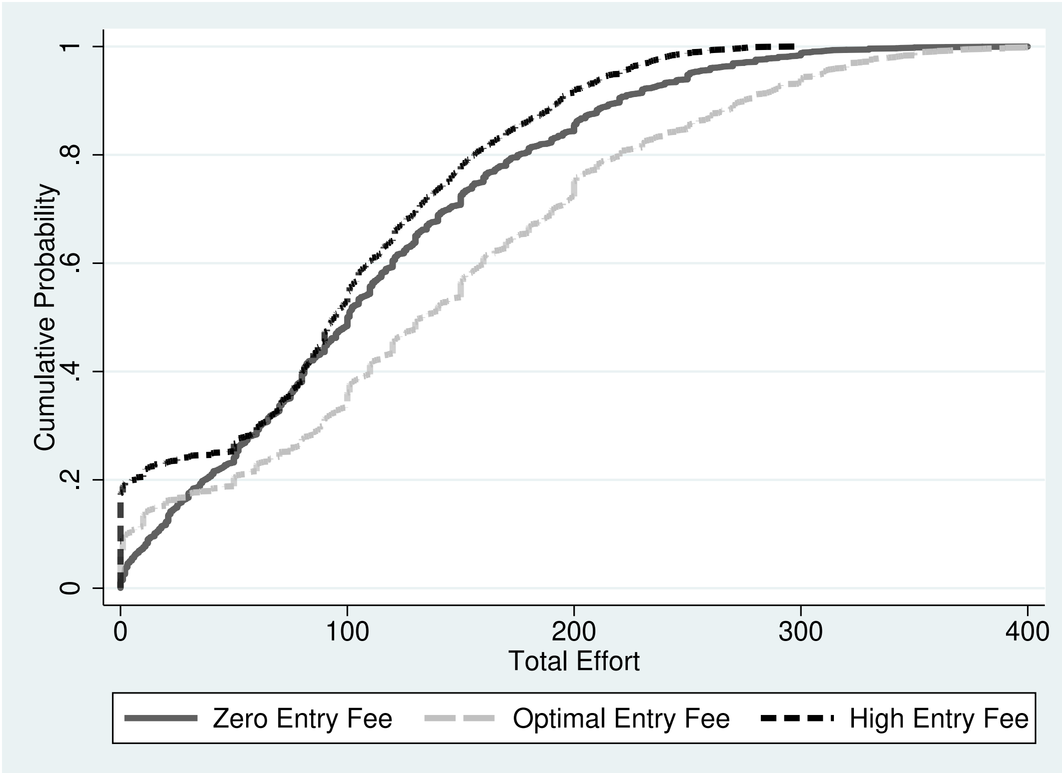

Figure 3: CDFs of Total Effort, All 30 Periods

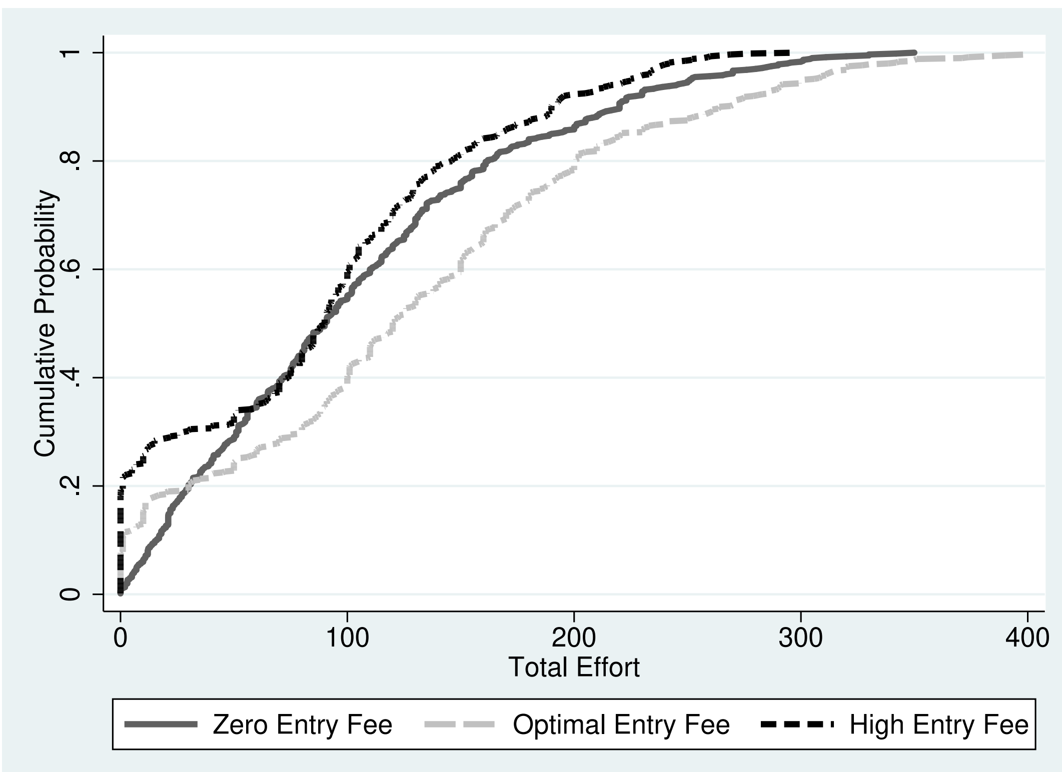

Figure 4: CDFs of Total Effort, Final 10 Periods

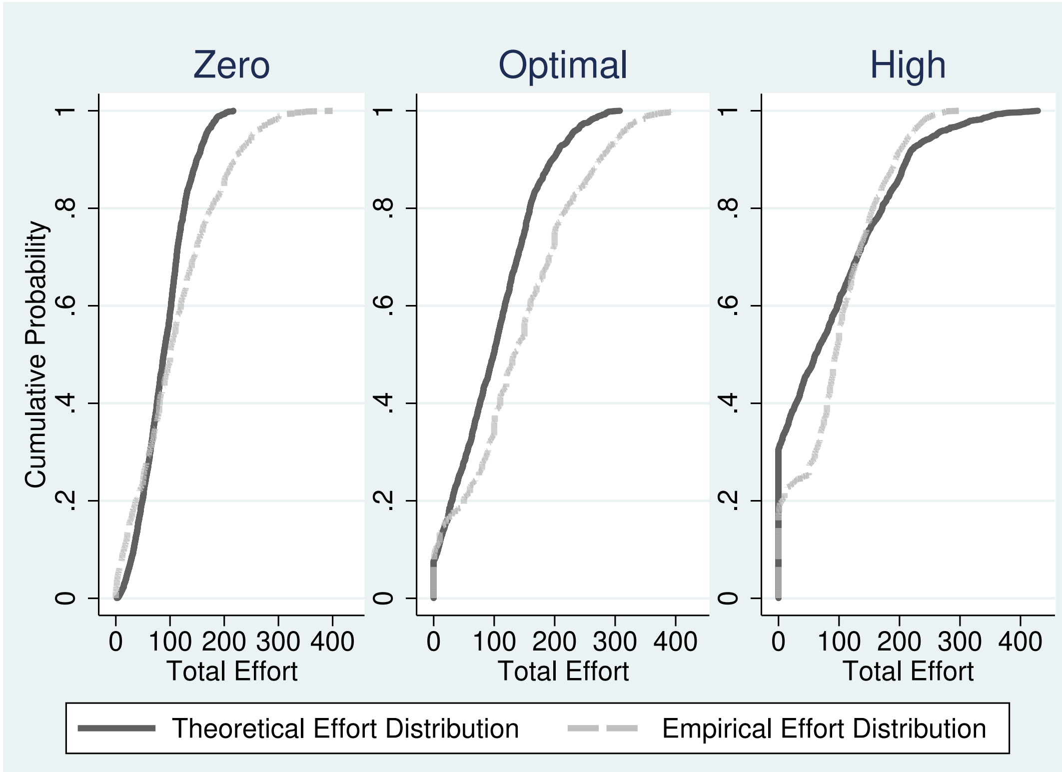

Figure 5: Theoretical and Empirical CDFs of Total Effort, All 30 Periods

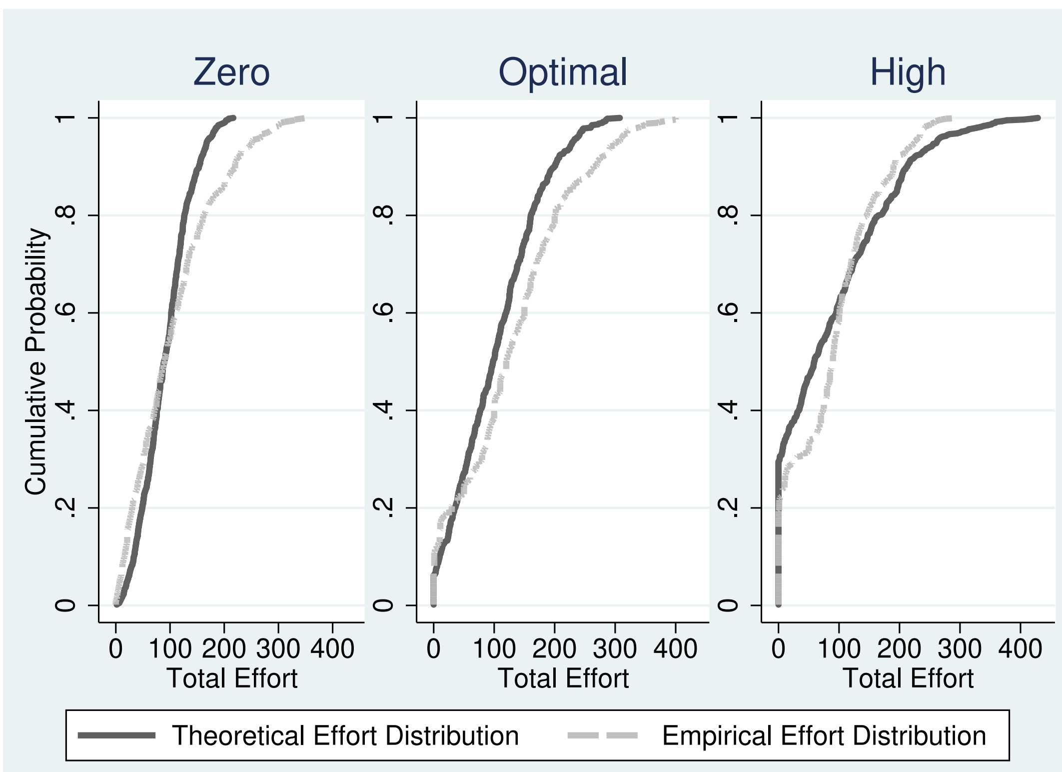

Figure 6: Theoretical and Empirical CDFs of Total Effort, Final 10 Periods

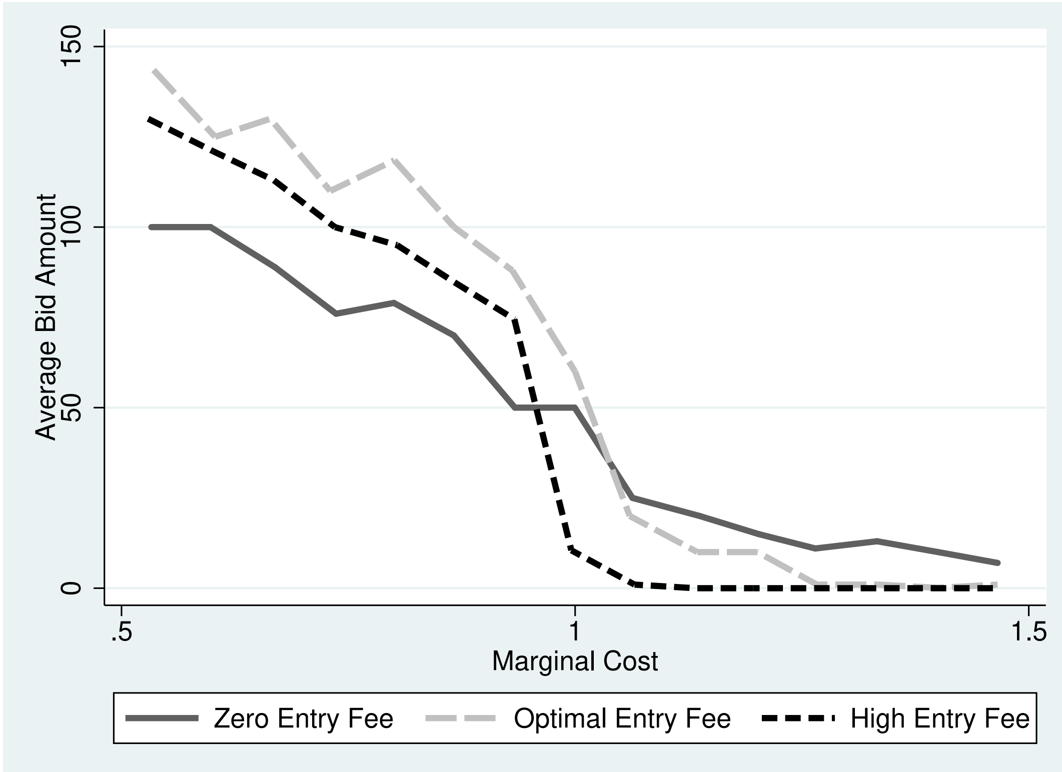

Figure 7: Average Bids of Entering Bidders, All 30 Periods

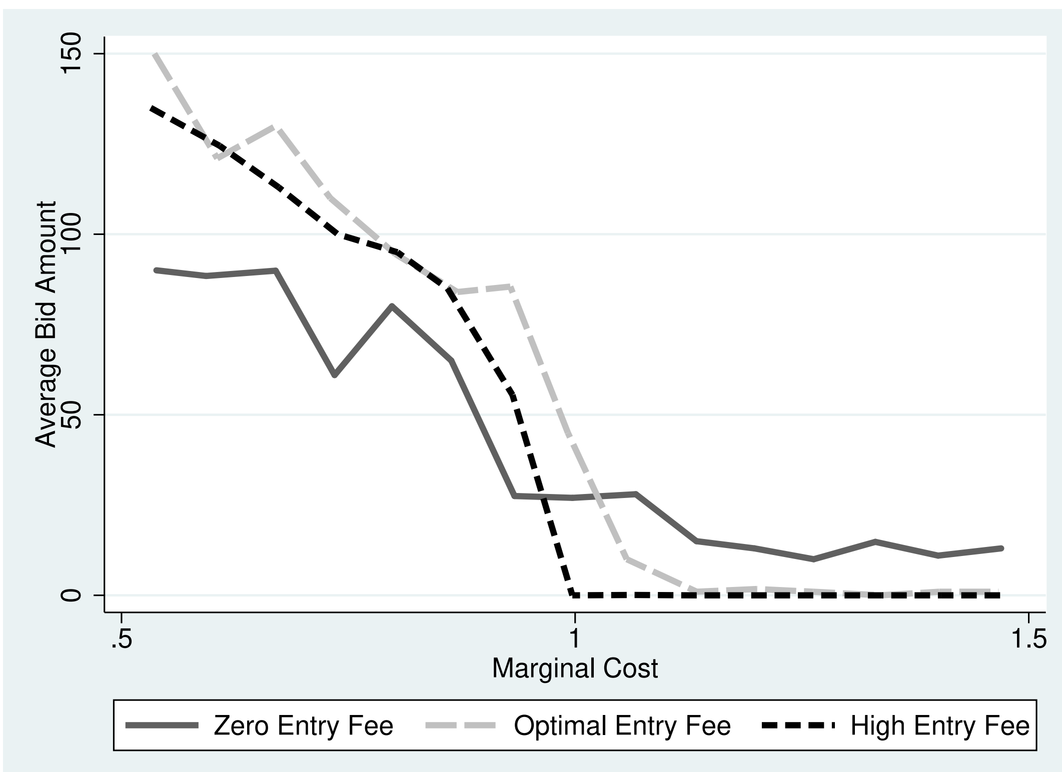

Figure 8: Average Bids of Entering Bidders, Final 10 Periods

the optimal entry fee (z-statistic = 3.15, p-value = 0.00). We note that, in our robustness checks discussed in Appendix D, we find different efficiency patterns for different cost distributions. As a result, we do not infer much about how efficiency varies with the entry fee.

Table 3 provides summary statistics for bidders' entry behavior: the number of entrants (Column (1)), excess entrants above the theoretically predicted number of entrants (Column (2)), the probability of entry for the high types who are predicted to enter (Column (3)), and the probability of entry for the low types who are not predicted to enter (Column (4)). Intuitively, entry decreases as the entry fee increases (z-statistic = 18.02, p-value = 0.00; z-statistic = 12.30, p-value = 0.00; zero relative to optimal and optimal relative to high, respectively). There is too little entry with no entry fee (z-statistic = 17.86, p-value = 0.00): theory predicts full entry, whereas our results suggest that a small number of contestants choose to stay out even in these treatments. Further, there is excess entry in the optimal entry fee treatment (z-statistic = 3.32, p-value = 0.00) and a large amount of excess entry in the high entry fee treatment (z-statistic = 18.22, p-value = 0.00).[10]

A useful way to understand the excess entry we find is to separate bidders into high types (whose costs are below the entry threshold and thus should enter) and low types (whose costs are above the threshold and thus should not enter). With no entry fee, all bidders are high types because there should be full entry. As shown in Column (3) of Table 3, bidders enter around 90% of the time with zero entry fee. Because of the all-pay nature of the auction, these non-entering bidders are likely those who would bid zero if they entered but instead chose not to enter. With a positive entry fee, between 36% and 53% of low types enter (whose entry probability is 0% in theory), while 82% to 89% of high types enter (whose entry probability is 100% in theory). We conclude that excess entry is driven by bidders with high marginal costs paying the entry fee to enter the contest, when their expected earnings upon entering do not justify doing so theoretically.

Overall, we find strong support for the opposing effects demonstrated by our theoretical results. An entry fee increases the bids of entering bidders, as seen by the steepening of the bid functions in Figure 7. But, an entry fee discourages entry, as seen by the entry probabilities in Table 3. In total, the optimal entry fee can raise revenue by appropriately balancing these two effects. We find that the optimal entry fee does exactly that and raises revenue by 26.75% relative to no entry fee

[10]To be clear, the statistical tests reported above regarding excess entry are one-sample Wilcoxon signed-ranks test. We test the number of excess entrants against zero to test whether entry is in line with theory.

and 46.16% relative to an entry fee that is set too high. We now support these aggregate results with an analysis at the level of individual bidders.

5.2 Individual-Level Results

Next, we present estimates at the individual level and repeat the analysis only considering the final 10 periods to account for subject learning. Table 5 presents conditional averages of bids and entry probabilities for each treatment. The bid estimation is an OLS regression that includes only those contestants who entered the contest, while the entry estimation is a Probit regression of whether the contestant entered. Standard errors are clustered at the subject-level to account for dependencies at the subject level.[11] The results shown in Table 5 are conditional averages in the sense that the regressions control for a host of subject characteristics as well as the treatment in which the subject participated. We calculate post-estimation conditional means to present the average bid and entry probability for each treatment, holding observable characteristics constant.

Table 5 clearly shows that the presence of entry fee discourages entry but induces higher bids from the participating bidders. The same pictures emerge when we restrict our attention to the final 10 periods. Average bids fall over the course of the experiment (comparing Column (1) to Column (3)) in all treatments. From Columns (1) and (3), conditional on entry, contestants bid meaningfully more when the entry fee is set optimally than when it is zero or when it is high. The pairwise comparisons of optimal entry fee treatments to zero or high entry fee treatments are all statistically significant (F-statistic = 45.02, p-value = 0.00; F-statistic = 5.08, p-value = 0.02; relative to zero and high, respectively). Even when considering only the final 10 periods, the optimal entry fee increases bids to a quantitatively significant degree (F-statistic = 30.73, p-value = 0.00; F-statistic = 7.33, p-value = 0.01; relative to zero and high, respectively). From Columns (2) and (4), contestants enter meaningfully less often when the entry fee increases. Again, all differences are large and statistically significant.[12]

Table 6 presents the individual-level regressions for bidding and entry decisions; these are the

[11] An alternative specification uses subject-level random effects within a panel-data regression model, that is, panel-data random-effects linear regression for bids and panel-data random-effects Probit regression for entry. These results are shown in Appendix C and are very similar to what is discussed below. See Tables C1 and C2.

[12] Statistical test results for the following comparisons, relative to zero all 30 periods, relative to high all 30 periods, relative to zero final 10 periods, relative to high final 10 periods, respectively, are as follows: F-statistics of 76.52, 170.79, 77.25, and 186.96. All four p-values are 0.00.

Table 5: Conditional Means of Bids and Probability of Entry for Each Treatment

	All 30 Periods		Final 10 Periods	
	(1) Bid if Enter	(2) Pr(Entry)	(3) Bid if Enter	(4) Pr(Entry)
Zero Entry Fee	61.068	0.902	55.031	0.939
	(2.670)	(0.011)	(2.723)	(0.011)
Optimal Entry Fee	94.495	0.739	86.778	0.735
	(3.084)	(0.017)	(3.872)	(0.022)
High Entry Fee	79.864	0.604	75.776	0.583
	(1.507)	(0.017)	(2.113)	(0.021)

Notes: Columns (1) and (2) include all periods, while Columns (3) and (4) include only the final 10 periods. Columns (1) and (3) display marginal effects from an OLS regression of the contestant's bid, conditional on entering the contest. Columns (2) and (4) display marginal effects from a Probit regression of whether the contestant entered the contest. These results are post-estimation conditional means, which present the average bid and entry probability for each treatment, holding observable characteristics constant. The regression specifications includes all experimental and demographic characteristics shown in Table 6.

same regressions that generated the conditional means discussed above. We controlled for the contestant's marginal cost in that period, the period, and several subject characteristics: probability test score (percent of questions correct on the post-experiment probability questionnaire), whether the subject has participated in previous economics experiments, whether the subject has previously taken a game theory course, whether the subject is risk averse, indicators for the subject's year of study, indicators for the subject's course of study, and whether the subject is female.[13] Continuous variables (marginal cost, period, and probability test score) are each included along with a quadratic term but marginal effects at the mean are shown. For the estimation of the probability of entry, marginal effects for all variables are shown.

In Table 6, the optimal entry fee significantly increases bids, with an effect size around 28 bid points, conditional on entry. Relative to the average bid in the zero entry fee treatments of 65.85 (59.31) points, an optimally set entry fee raises bids by 42.38% (44.56%) in all 30 periods (final 10 periods). Higher entry fees reduce entry, with the effect size of the optimal entry fee relative to no entry fee of about 18 percentage points. Turning to covariates of interest, higher marginal bidding costs are associated with lower bids and lower probability of entry (a marginal cost that is one unit higher reduces bids by nearly 100 points and reduces entry by around 49 percentage points). The

[13]Based on the multiple-price list risk elicitation of Holt and Laury (2002), a subject is considered risk averse who switches from the safe lottery to the risky lottery later than the fifth of ten rows.

effect of the period variable indicates that subjects learn to lower their bids to a moderate degree (by approximately 0.7 points per round when considering all 30 periods). There is no trend within the experiment in terms of the rate of entry.

For subject characteristics, demonstrating a better understanding of probability is correlated with less entry, suggesting that some part of the over-entry we observe is driven by cognitive differences among subjects. Previous experimental experience reduces bids and lowers entry probabilities, with large effect sizes; thus, subject experience from participation in previous experiments may play a role in ameliorating overbidding and excess entry. Knowledge of game theory reduces bids, though the effect falls over the course of the experiment, but has little effect on entry. Next, risk averse subjects enter at a lower rate, consistent with our intuition that risk aversion affects willingness to participate in all-pay auctions in which ex post earnings are highly variable. Older subjects bid more and have slightly larger entry probabilities, relative to younger subjects. A subject's course of study has little effect on bidding, but engineering students enter more often than those in business, liberal arts (the omitted group), or science.

Finally, there is strong evidence that female subjects bid more, resulting in lower profits, and weak evidence that they enter at a higher rate. Concerning bidding behavior, several authors have found gender differences in bidding behavior in environments without endogenous entry (Chen, Katuščák, and Ozdenoren, 2013; Schipper, 2014; Chen, Ong, and Sheremeta, 2015; Price and Sheremeta, 2015).

6 Conclusions

Contests are an important class of performance evaluation mechanisms. We introduce a new contest format and consider its theoretical and empirical properties. Contestants whose abilities are their private information can choose to pay an entry fee to participate in a contest where the initial prize is augmented with the sum of entrants' entry fees. Our theoretical analysis shows that the principal can induce higher effort by setting a positive and finite entry fee. The optimal entry fee balances the entry-discouraging effect of an entry fee with the incentive effect of a larger prize (due to the prize-augmenting entry fee). Our experimental results confirm the revenue advantage of the optimal entry fee. These results are consistent with observed practice in the sense that entry fees are widely observed in contests in the field. We conclude that contest designers find entry fees to be an efficient approach for increasing effort provision in environments such as sporting competitions (e.g., marathons and poker tournaments) and contests in the creative industries (e.g., writing, photography, architecture, and design).

For future research, it may be interesting to extend the experimental analysis to the case of more than two contestants. Note however that the theory predicts that the optimal entry fee is positive and finite, irrespective of the number of contestants. The gender differences we found are an additional aspect of our analysis that may be worth further investigation. In these data, female bidders bid more aggressively in a way that results in lower profits for female bidders relative to male bidders. Further, female bidders tend to enter the competition at a higher rate than male bidders. See Chen, Ong, and Sheremeta (2015) and Price and Sheremeta (2015) for experimental analyses that provide more in depth analysis of the role of gender.

Table 6: Individual-Level Regression Results for Bids and Entry

	All 30 Periods		Final 10 Periods	
	(1) Bid if Enter	(2) Pr(Entry)	(3) Bid if Enter	(4) Pr(Entry)
Optimal Entry Fee	27.908	-0.176	26.429	-0.223
	(4.159)***	(0.020)***	(4.768)***	(0.025)***
High Entry Fee	7.705	-0.292	10.882	-0.352
	(3.418)**	(0.022)***	(4.020)***	(0.026)***
Marginal Cost	-100.848	-0.491	-109.995	-0.471
	(3.066)***	(0.020)***	(4.432)***	(0.026)***
Period	-0.667	-0.000	0.057	0.003
	(0.085)***	(0.001)	(0.262)	(0.002)
Probability Test Score	-8.057	-0.125	-2.570	-0.140
	(7.294)	(0.050)**	(8.457)	(0.059)**
Past Experiments	-14.899	-0.063	-19.914	-0.055
	(4.428)***	(0.023)***	(5.166)***	(0.030)*
Had Game Theory	-7.162	0.014	-3.847	-0.011
	(3.433)**	(0.020)	(4.358)	(0.025)
Risk Averse Subject	-1.094	-0.035	0.353	-0.069
	(3.052)	(0.019)*	(3.518)	(0.023)***
Subject's Age	2.419	0.012	3.230	0.006
	(1.188)**	(0.007)*	(1.385)**	(0.008)
Engineering Student	-7.191	0.061	-1.100	0.071
	(5.329)	(0.024)**	(5.995)	(0.031)**
Science Student	-12.327	0.030	-4.741	0.060
	(4.932)**	(0.025)	(5.730)	(0.030)*
Business Student	-1.314	0.037	0.153	0.051
	(4.998)	(0.024)	(6.046)	(0.030)*
Female Subject	8.339	0.044	7.022	0.014
	(3.455)**	(0.021)**	(4.028)*	(0.025)
N	8097	10800	2712	3600
Log Likelihood	-41,733.075	-4,488.870	-13,969.196	-1,388.561

Notes: Columns (1) and (2) include all periods, while Columns (3) and (4) include only the final 10 periods. Columns (1) and (3) display marginal effects from an OLS regression of the contestant's bid, conditional on entering the contest. Columns (2) and (4) display marginal effects from a Probit regression of whether the contestant entered the contest. $*$, $**$, and $***$ denote significance at the 10%, 5%, and 1% level, respectively.

References

Anderson, L. R., and S. L. Stafford (2003): "An experimental analysis of rent seeking under varying competitive conditions," *Public Choice*, 115(1-2), 199–216.

Barut, Y., D. Kovenock, and C. N. Noussair (2002): "A Comparison of Multiple-Unit All-Pay and Winner-Pay Auctions Under Incomplete Information," *International Economic Review*, 43(3), 675–708.

Cason, T. N., W. A. Masters, and R. M. Sheremeta (2010): "Entry into winner-take-all and proportional-prize contests: An experimental study," *Journal of Public Economics*, 94(9), 604–611.

Chen, Y., P. Katušcák, and E. Ozdenoren (2013): "Why Can't a Woman Bid More Like a Man?," *Games and Economic Behavior*, 77(1), 181–213.

Chen, Z. C., D. Ong, and R. M. Sheremeta (2015): "The gender difference in the value of winning," *Economics Letters*, 137, 226–229.

Clark, D. J., and C. Riis (1998): "Influence and the discretionary allocation of several prizes," *European Journal of Political Economy*, 14(4), 605–625.

Davis, D. D., and R. J. Reilly (1998): "Do too many cooks always spoil the stew? An experimental analysis of rent-seeking and the role of a strategic buyer," *Public Choice*, 95(1-2), 89–115.

Dechenaux, E., D. Kovenock, and R. M. Sheremeta (2014): "A survey of experimental research on contests, all-pay auctions and tournaments," *Experimental Economics*, pp. 1–61.

Fischbacher, U. (2007): "z-Tree: Zurich Toolbox for Ready-Made Economic Experiments," *Experimental Economics*, 10(2), 171–178.

Fréchette, G. R. (2012): "Session-effects in the laboratory," *Experimental Economics*, 15(3), 485–498.

Fredriksson, K. (1993): *American rodeo: from Buffalo Bill to big business*. Texas A&M University Press.

Fullerton, R. L., and R. P. McAfee (1999): "Auctioning entry into tournaments," *Journal of Political Economy*, 107(3), 573–605.

Gradstein, M. (1995): "Intensity of competition, entry and entry deterrence in rent seeking contests," *Economics & Politics*, 7(1), 79–91.

Harrison, G. W. (1989): "Theory and Misbehavior of First-price Auctions," *American Economic Review*, pp. 749–762.

Holt, C. A., and S. K. Laury (2002): "Risk Aversion and Incentive Effects," *American Economic Review*, 92(5), 1644–1655.

Liu, B., J. Lu, R. Wang, and J. Zhang (2018): "Optimal prize allocation in contests: The role of negative prizes," *Journal of Economic Theory*, 175, 291–317.

Llorente-Saguer, A., R. M. Sheremeta, and N. Szech (2016): "Designing contests between heterogeneous contestants: An experimental study of tie-breaks and bid-caps in all-pay auctions," https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2811045.

Megidish, R., and A. Sela (2013): "Allocation of Prizes in Contests with Participation Constraints," *Journal of Economics & Management Strategy*, 22(4), 713–727.

Minor, D. B. (2013): "Increasing revenue through rewarding the best less (or not at all)," https://scholar.google.com.sg/scholar?q=related:aJZwNAG9tgMJ:scholar.google.com/.

Moldovanu, B., and A. Sela (2001): "The optimal allocation of prizes in contests," *American Economic Review*, pp. 542–558.

——— (2006): "Contest architecture," *Journal of Economic Theory*, 126(1), 70–96.

Moldovanu, B., A. Sela, and X. Shi (2007): "Contests for status," *Journal of Political Economy*, 115(2), 338–363.

——— (2012): "Carrots and sticks: prizes and punishments in contests," *Economic Inquiry*, 50(2), 453–462.

Müller, W., and A. Schotter (2010): "Workaholics and dropouts in organizations," *Journal of the European Economic Association*, 8(4), 717–743.

Noussair, C., and J. Silver (2006): "Behavior in all-pay auctions with incomplete information," *Games and Economic Behavior*, 55(1), 189–206.

Price, C. R., and R. M. Sheremeta (2015): "Endowment origin, demographic effects, and individual preferences in contests," *Journal of Economics & Management Strategy*, 24(3), 597–619.

Schipper, B. C. (2014): "Sex Hormones and Competitive Bidding," *Management Science*, 61(2), 249–266.

Schotter, A., and K. Weigelt (1992): "Asymmetric tournaments, equal opportunity laws, and affirmative action: Some experimental results," *The Quarterly Journal of Economics*, pp. 511–539.

Sheremeta, R. M. (2011): "Contest design: An experimental investigation," *Economic Inquiry*, 49(2), 573–590.

Stracke, R., W. Höchtl, R. Kerschbamer, and U. Sunde (2014): "Optimal Prizes in Dynamic Elimination Contests: An Experimental Analysis," *Journal of Economic Behavior & Organization*, 102, 43–58.

Thomas, J. P., and Z. Wang (2013): "Optimal punishment in contests with endogenous entry," *Journal of Economic Behavior & Organization*, 91, 34–50.

Vandegrift, D., A. Yavas, and P. M. Brown (2007): "Incentive effects and overcrowding in tournaments: An experimental analysis," *Experimental Economics*, 10(4), 345–368.

Appendix A Proofs

Proof of Corollary 1. The expected total effort as a function of the entry fee E is

$$\begin{aligned}
& TE(E) \\
= \; & N \int_{\underline{c}}^{\overline{c}} b(c;E) f(c) dc \\
= \; & N \int_{\underline{c}}^{\hat{c}(E)} \int_{c}^{\hat{c}(E)} \frac{f(t)}{t} \sum_{n=1}^{N-1} C_{N-1}^{n} [1-F(\hat{c}(E))]^{(N-1)-n} n [F(\hat{c}(E)) - F(t)]^{n-1} V_{n+1}(E) dt f(c) dc \\
= \; & N \int_{\underline{c}}^{\hat{c}(E)} \int_{c}^{\hat{c}(E)} \frac{f(t)}{t} \sum_{n=1}^{N-1} C_{N-1}^{n} [1-F(\hat{c}(E))]^{(N-1)-n} n [F(\hat{c}(E)) - F(t)]^{n-1} V_{n+1}(E) f(c) dt dc \\
= \; & N \int_{\underline{c}}^{\hat{c}(E)} \int_{\underline{c}}^{t} \frac{f(t)}{t} \sum_{n=1}^{N-1} C_{N-1}^{n} [1-F(\hat{c}(E))]^{(N-1)-n} n [F(\hat{c}(E)) - F(t)]^{n-1} V_{n+1}(E) f(c) dc dt \\
= \; & N \int_{\underline{c}}^{\hat{c}(E)} \frac{f(t)}{t} \sum_{n=1}^{N-1} C_{N-1}^{n} [1-F(\hat{c}(E))]^{(N-1)-n} n [F(\hat{c}(E)) - F(t)]^{n-1} V_{n+1}(E) F(t) dt.
\end{aligned}$$

□

Proof of Proposition 2. From $TE(E)$ in Corollary 1, we have

$$\begin{aligned}
& \frac{TE'(E)}{N} \\
= \; & \int_{\underline{c}}^{\hat{c}(E)} \frac{f(t)}{t} \sum_{n=1}^{N-1} C_{N-1}^{n} [1-F(\hat{c}(E))]^{(N-1)-n} n(n+1) [F(\hat{c}(E)) - F(t)]^{n-1} F(t) dt \\
& + \Big\{ \frac{f(\hat{c}(E))}{\hat{c}(E)} \sum_{n=1}^{N-1} C_{N-1}^{n} [1-F(\hat{c}(E))]^{(N-1)-n} n [F(\hat{c}(E)) - F(\hat{c}(E))]^{n-1} V_{n+1}(E) F(\hat{c}(E)) \\
& - \int_{\underline{c}}^{\hat{c}(E)} \frac{f(t)}{t} \sum_{n=1}^{N-1} C_{N-1}^{n} (N-1-n) [1-F(\hat{c}(E))]^{N-n-2} f(\hat{c}(E)) n [F(\hat{c}(E)) - F(t)]^{n-1} V_{n+1}(E) F(t) dt \\
& + \int_{\underline{c}}^{\hat{c}(E)} \frac{f(t)}{t} \sum_{n=1}^{N-1} C_{N-1}^{n} (n-1) [1-F(\hat{c}(E))]^{N-n-1} f(\hat{c}(E)) n [F(\hat{c}(E)) - F(t)]^{n-2} V_{n+1}(E) F(t) dt \Big\} \hat{c}'(E).
\end{aligned}$$

It suffices to show that the limit of the above expression is strictly positive when $E \to 0$. To this end, we first show that when $E \to 0$ the first integral (the first term) is strictly larger than $\frac{1}{\underline{c}}$, and then show that the limit of the sum of the other terms is $-\frac{1}{\underline{c}}$.

Note that $\lim_{E\to 0}\hat{c}(E)=\overline{c}$ and $\lim_{E\to 0}F(\hat{c}(E))=1$. For the first integral, we have

$$\begin{aligned}
& \lim_{E\to 0}\int_{\underline{c}}^{\hat{c}(E)}\frac{f(t)}{t}\sum_{n=1}^{N-1}C_{N-1}^{n}[1-F(\hat{c}(E))]^{(N-1)-n}n(n+1)[F(\hat{c}(E))-F(t)]^{n-1}F(t)dt \\
= & \int_{\underline{c}}^{\overline{c}}\frac{f(t)}{t}C_{N-1}^{N-1}N(N-1)[1-F(t)]^{N-2}F(t)dt > \int_{\underline{c}}^{\overline{c}}\frac{f(t)}{\overline{c}}C_{N-1}^{N-1}N(N-1)[1-F(t)]^{N-2}F(t)dt \\
= & \frac{N(N-1)}{\overline{c}}\int_0^1 y(1-y)^{N-2}dy = \frac{N(N-1)}{\overline{c}}\int_0^1[(1-y)^{N-2}-(1-y)^{N-1}]dy \\
= & \frac{N(N-1)}{\overline{c}}\cdot(\frac{1}{N-1}-\frac{1}{N}) = \frac{1}{\overline{c}}.
\end{aligned}$$

The sum of the rest terms (other than the first integral) in $\frac{TE'(E)}{N}$ is

$$\begin{aligned}
& \beta(E) \\
= & \Big\{\frac{f(\hat{c}(E))}{\hat{c}(E)}\sum_{n=1}^{N-1}C_{N-1}^{n}[1-F(\hat{c}(E))]^{(N-1)-n}n[F(\hat{c}(E))-F(\hat{c}(E))]^{n-1}V_{n+1}(E)F(\hat{c}(E)) \\
& -\int_{\underline{c}}^{\hat{c}(E)}\frac{f(t)}{t}\sum_{n=1}^{N-1}C_{N-1}^{n}(N-1-n)[1-F(\hat{c}(E))]^{N-n-2}f(\hat{c}(E))n[F(\hat{c}(E))-F(t)]^{n-1}V_{n+1}(E)F(t)dt \\
& +\int_{\underline{c}}^{\hat{c}(E)}\frac{f(t)}{t}\sum_{n=1}^{N-1}C_{N-1}^{n}(n-1)[1-F(\hat{c}(E))]^{N-n-1}f(\hat{c}(E))n[F(\hat{c}(E))-F(t)]^{n-2}V_{n+1}(E)F(t)dt\Big\}\hat{c}'(E).
\end{aligned}$$

Recall that $V_{n+1}(E)=V+(n+1)E$. We thus have

$$\begin{aligned}
& \beta(E) \\
= & \frac{f(\hat{c}(E))}{\hat{c}(E)}\sum_{n=1}^{N-1}C_{N-1}^{n}[1-F(\hat{c}(E))]^{(N-1)-n}n[F(\hat{c}(E))-F(\hat{c}(E))]^{n-1}[V+(n+1)E]F(\hat{c}(E))\hat{c}'(E) \\
& +\Big\{\int_{\underline{c}}^{\hat{c}(E)}\frac{f(t)}{t}\sum_{n=1}^{N-1}C_{N-1}^{n}(n-1)[1-F(\hat{c}(E))]^{N-n-1}f(\hat{c}(E))n[F(\hat{c}(E))-F(t)]^{n-2}F(t)dt \\
& -\int_{\underline{c}}^{\hat{c}(E)}\frac{f(t)}{t}\sum_{n=1}^{N-1}C_{N-1}^{n}(N-1-n)[1-F(\hat{c}(E))]^{N-n-2}f(\hat{c}(E))n[F(\hat{c}(E))-F(t)]^{n-1}F(t)dt\Big\}V\hat{c}'(E) \\
& +\int_{\underline{c}}^{\hat{c}(E)}\frac{f(t)}{t}\sum_{n=1}^{N-1}C_{N-1}^{n}(n-1)[1-F(\hat{c}(E))]^{N-n-1}E\hat{c}'(E)f(\hat{c}(E))n(n+1)[F(\hat{c}(E))-F(t)]^{n-2}F(t)dt \\
& -\int_{\underline{c}}^{\hat{c}(E)}\frac{f(t)}{t}\sum_{n=1}^{N-1}C_{N-1}^{n}(N-1-n)[1-F(\hat{c}(E))]^{N-n-2}E\hat{c}'(E)f(\hat{c}(E))n(n+1)[F(\hat{c}(E))-F(t)]^{n-1}F(t)dt.
\end{aligned}$$

We need to show that $\lim_{E\to 0}\beta(E) = -\frac{1}{\overline{c}}$. Recall that $\hat{c}(E) = F^{-1}[1-(\frac{E}{V+E})^{\frac{1}{N-1}}]$. We thus have

$$\hat{c}'(E) = -\frac{(\frac{E}{V+E})^{\frac{1}{N-1}-1}\frac{V}{(V+E)^2}}{(N-1)f(F^{-1}(1-(\frac{E}{V+E})^{\frac{1}{N-1}}))}.$$

We first show that

$$\lim_{E\to 0} f(\hat{c}(E))E\hat{c}'(E) = 0. \tag{1}$$

This is true because

$$\lim_{E\to 0} f(\hat{c}(E))E\hat{c}'(E) = -\lim_{E\to 0}\frac{(\frac{E}{V+E})^{\frac{1}{N-1}-1}\frac{VE}{(V+E)^2}}{N-1} = -\frac{1}{N-1}\lim_{E\to 0}(\frac{E}{V+E})^{\frac{1}{N-1}} = 0.$$

Note that $\lim_{E\to 0}\hat{c}(E) = \overline{c}$ and $\lim_{E\to 0} F(\hat{c}(E)) = 1$. Since (1) is true, we have

$$\lim_{E\to 0} E\hat{c}'(E)f(\hat{c}(E))[1-F(\hat{c}(E))]^n = 0,\ \forall n \geq 0. \tag{2}$$

We thus have that the limit of the last two terms in $\beta(E)$ is zero, i.e.,

$$\lim_{E\to 0}\int_{\underline{c}}^{\hat{c}(E)}\frac{f(t)}{t}\sum_{n=1}^{N-1}C_{N-1}^{n}(n-1)[1-F(\hat{c}(E))]^{N-n-1}E\hat{c}'(E)f(\hat{c}(E))n(n+1)[F(\hat{c}(E))-F(t)]^{n-2}F(t)dt = 0,$$

and

$$\lim_{E\to 0}\int_{\underline{c}}^{\hat{c}(E)}\frac{f(t)}{t}\sum_{n=1}^{N-1}C_{N-1}^{n}(N-1-n)[1-F(\hat{c}(E))]^{N-n-2}E\hat{c}'(E)f(\hat{c}(E))n(n+1)[F(\hat{c}(E))-F(t)]^{n-1}F(t)dt = 0.$$

We now show that the second term in $\beta(E)$ is zero, i.e.,

$$\begin{aligned} &\Big\{\int_{\underline{c}}^{\hat{c}(E)}\underbrace{\frac{f(t)}{t}\sum_{n=1}^{N-1}C_{N-1}^{n}(n-1)[1-F(\hat{c}(E))]^{N-n-1}f(\hat{c}(E))n[F(\hat{c}(E))-F(t)]^{n-2}F(t)dt}_{A_1} \\ &-\int_{\underline{c}}^{\hat{c}(E)}\underbrace{\frac{f(t)}{t}\sum_{n=1}^{N-1}C_{N-1}^{n}(N-1-n)[1-F(\hat{c}(E))]^{N-n-2}f(\hat{c}(E))n[F(\hat{c}(E))-F(t)]^{n-1}F(t)dt}_{A_2}\Big\}V\hat{c}'(E) \\ = \ & 0. \end{aligned}$$

This is true because $A_1 = A_2$:

$$\begin{aligned}
A_1 &= \frac{f(t)f(\hat{c}(E))F(t)}{t}\sum_{n=1}^{N-1} C_{N-1}^{n}(n-1)[1-F(\hat{c}(E))]^{N-n-1}n[F(\hat{c}(E))-F(t)]^{n-2} \\
&= \frac{f(t)f(\hat{c}(E))F(t)}{t}\sum_{n=2}^{N-1} C_{N-1}^{n}n(n-1)[1-F(\hat{c}(E))]^{N-n-1}[F(\hat{c}(E))-F(t)]^{n-2} \\
&= \frac{f(t)f(\hat{c}(E))F(t)}{t}\cdot(N-1)(N-2)\sum_{n=2}^{N-1} C_{N-3}^{n-2}[1-F(\hat{c}(E))]^{N-n-1}[F(\hat{c}(E))-F(t)]^{n-2} \\
&= \frac{f(t)f(\hat{c}(E))F(t)}{t}\cdot(N-1)(N-2)\{[1-F(\hat{c}(E))]+[F(\hat{c}(E))-F(t)]\}^{N-3} \\
&= \frac{f(t)f(\hat{c}(E))F(t)}{t}\cdot(N-1)(N-2)[1-F(t)]^{N-3},
\end{aligned}$$

$$\begin{aligned}
A_2 &= \frac{f(t)f(\hat{c}(E))F(t)}{t}\sum_{n=1}^{N-1} C_{N-1}^{n}(N-1-n)[1-F(\hat{c}(E))]^{N-n-2}n[F(\hat{c}(E))-F(t)]^{n-1} \\
&= \frac{f(t)f(\hat{c}(E))F(t)}{t}\sum_{n=1}^{N-2} C_{N-1}^{n}n(N-1-n)[1-F(\hat{c}(E))]^{N-n-2}[F(\hat{c}(E))-F(t)]^{n-1} \\
&= \frac{f(t)f(\hat{c}(E))F(t)}{t}\cdot(N-1)(N-2)\sum_{n=1}^{N-2} C_{N-3}^{n-1}[1-F(\hat{c}(E))]^{N-n-2}[F(\hat{c}(E))-F(t)]^{n-1} \\
&= \frac{f(t)f(\hat{c}(E))F(t)}{t}\cdot(N-1)(N-2)[1-F(t)]^{N-3}.
\end{aligned}$$

Recall $\lim_{E\to 0} F(\hat{c}(E)) = 1$. Based on the above results, we have

$$\begin{aligned}
&\lim_{E\to 0}\beta(E) \\
=\ & \lim_{E\to 0}\frac{f(\hat{c}(E))}{\hat{c}(E)}\sum_{n=1}^{N-1} C_{N-1}^{n}[1-F(\hat{c}(E))]^{(N-1)-n}n[F(\hat{c}(E))-F(\hat{c}(E))]^{n-1}[V+(n+1)E]F(\hat{c}(E))\hat{c}'(E) \\
=\ & \lim_{E\to 0}\frac{f(\hat{c}(E))}{\hat{c}(E)}C_{N-1}^{1}[1-F(\hat{c}(E))]^{N-2}(V+2E)F(\hat{c}(E))\hat{c}'(E) \\
=\ & V\lim_{E\to 0}\frac{f(\hat{c}(E))}{\hat{c}(E)}C_{N-1}^{1}[1-F(\hat{c}(E))]^{N-2}F(\hat{c}(E))\hat{c}'(E) \\
=\ & -\frac{(N-1)V}{\bar{c}}\lim_{E\to 0}[1-F(\hat{c}(E))]^{N-2}\frac{(\frac{E}{V+E})^{\frac{1}{N-1}-1}\frac{V}{(V+E)^2}}{N-1} \\
=\ & -\frac{1}{\bar{c}}\lim_{E\to 0}(\frac{E}{V+E})^{\frac{N-2}{N-1}}(\frac{E}{V+E})^{\frac{1}{N-1}-1} = -\frac{1}{\bar{c}}.
\end{aligned}$$

This completes the proof. $\square$

Proof of Proposition 3. Recall that

$$TE(E) = N \int_{\underline{c}}^{\hat{c}(E)} \frac{f(t)}{t} \sum_{n=1}^{N-1} C_{N-1}^{n} [1 - F(\hat{c}(E))]^{(N-1)-n} n [F(\hat{c}(E)) - F(t)]^{n-1} V_{n+1}(E) F(t) dt,$$

where $\hat{c}(E) = F^{-1}[1 - (\frac{E}{V+E})^{\frac{1}{N-1}}]$. The above term is strictly positive. Further notice that

$$\begin{aligned}
& \sum_{n=1}^{N-1} C_{N-1}^{n} [1 - F(\hat{c}(E))]^{(N-1)-n} n [F(\hat{c}(E)) - F(t)]^{n-1} V_{n+1}(E) \\
= \; & (N-1) \sum_{n=1}^{N-1} C_{N-2}^{n-1} [1 - F(\hat{c}(E))]^{(N-1)-n} [F(\hat{c}(E)) - F(t)]^{n-1} V_{n+1}(E) \\
< \; & (N-1) \sum_{n=1}^{N-1} C_{N-2}^{n-1} [1 - F(\hat{c}(E))]^{(N-1)-n} [F(\hat{c}(E)) - F(t)]^{n-1} V_{N}(E) \\
= \; & (N-1)[1 - F(t)]^{N-2} V_N(E) \leq (N-1) V_N(E).
\end{aligned}$$

To show that the optimal entry fee is finite, it suffices to show that $\lim_{E \to \infty} TE(E) = 0$. To this end, note that

$$\begin{aligned}
0 \; < \; & TE(E) < N(N-1) V_N(E) \int_{\underline{c}}^{\hat{c}(E)} \frac{f(t)}{t} F(t) dt \\
< \; & \frac{N(N-1) V_N(E)}{\underline{c}} \int_{\underline{c}}^{\hat{c}(E)} f(t) F(t) dt = \frac{N(N-1) V_N(E) F^2(\hat{c}(E))}{2\underline{c}}.
\end{aligned}$$

If the limit of the last expression is zero, the proof is done. In fact, since $\lim_{E \to \infty} F(\hat{c}(E)) = 0$, we only need to show that

$$\lim_{E \to \infty} E F^2(\hat{c}(E)) = 0. \tag{3}$$

If we can show that

$$\lim_{E \to \infty} E F(\hat{c}(E)) < M,$$

where M is some finite number, then (3) holds.

In fact, recall that

$$F((\hat{c}(E)) = 1 - (\frac{E}{V+E})^{\frac{1}{N-1}}.$$

Thus,

$$
\begin{aligned}
& \lim_{E\to\infty} EF(\hat{c}(E)) \\
= \quad & \lim_{E\to\infty} \frac{1-(\frac{E}{V+E})^{\frac{1}{N-1}}}{\frac{1}{E}} \\
= \quad & \lim_{E\to\infty} \frac{\frac{1}{N-1}(\frac{E}{V+E})^{\frac{1}{N-1}-1}\frac{V}{(V+E)^2}}{\frac{1}{E^2}} \\
= \quad & \lim_{E\to\infty} \frac{1}{N-1}(\frac{E}{V+E})^{\frac{1}{N-1}-1}\frac{VE^2}{(V+E)^2} \\
= \quad & \frac{V}{N-1}.
\end{aligned}
$$

This completes the proof. □

Appendix B Experimental Instructions

The following instructions correspond to the entry fee treatments.

General Instructions

Thank you for participating in this study! Please pay attention to the information provided here and make your decisions carefully. If at any time you have questions to ask, please raise your hand and an experimenter will come to you.

Please do not communicate with other participants at any point in this study. Failure to adhere to this rule would force us to stop this study and you will be asked to leave the experiment without pay.

All information collected will be kept strictly confidential and used for the sole purpose of this study.

Specific Stage-by-Stage Instructions

We estimate the total duration of this study to be approximately 1.5 hours. All incentives will be denominated in experimental dollars (expressed as ECU), which will be added to and subtracted from the balance in your "checkbook" as the experiment progresses. The final amount of experimental dollars in your checkbook at the end of the experiment's money-earning stages will be converted to real dollars using the conversion rule mentioned in the later part of this instruction. On top of your final earning, you will earn S$2 show-up.

You will participate in the following stages:

Stage 1

You will interact with other participants anonymously through the computer interface for a number of periods. Each participant will only be identified by his or her unique numerical ID displayed on the participant's computer screen throughout the experiment.

In each period, you will be randomly matched with another participant to form a pair. You and the other participant will compete against each other in a bidding contest to win prize money (V), which is equal to 100 ECU. You and your opponent can decide whether or not to participate in the contest. If you decide to participate in the contest, you must pay an entry fee (E). The amount of entry fee will be indicated in your computer screen.

The total amount of entry fees collected from all participating contestants will be added into the prize money (V).

When you decide to participate in the contest, you will have to submit a costly bid. Your total bidding cost is equal to

Cost = c * bid

where c is the additional cost you need to incur per additional dollar of bid. We call it cost rate; and bid is the amount of your bid. To cover your total bidding cost, each of you is given a checkbook of 200 ECU in every period.

Your cost rate c can take any value from 0.5 to 1.5 (up to 2 decimal points). The computer will randomly draw the value of your cost rate. All values from 0.5 to 1.5 have an equal chance of being selected as your cost rate. You will only know your own cost rate c, but not your opponent's cost rate.

- If you decide to participate in the contest and submit a non-zero bid, your total cost incurred will be equal to:

  Entry Fee (**E**) + your bidding cost (**c*Bid**).

- If both of you participate in the contest, whoever submit the highest bid wins the contest. The winning prize will be;

  100 + 2*Entry Fee

- If it is only you who participates in the contest, you automatically win the contest. The winning prize value will be;

  100 + Entry Fee

  If you submit the same bid amount as your opponent, the contest ends in a tie, the computer will randomly select a winner. Both of you will have an equal chance of being selected as the winner. The winning prize will be;

  100 + 2*Entry Fee

- If you decide not to participate in the contest (i.e. submit zero bid), your earnings from the contest will be zero.

Five periods out of all periods will be drawn randomly to determine your payoff from Stage 1. The earnings you received in these five drawn periods will be summed and converted into SGD equivalent with the following conversion rule:

60 ECU = $ 1,

and added to your final earnings from this experiment when the experiment is completed.

Stage 2

In this part of the study you will be asked to make a series of choices. How much you receive will depend partly on chance and partly on the choices you make. The decision problems are not designed to test you. What we want to know is what choices you would make in them. The only right answer is what you really would choose.

For each line in the table you will see in this stage, please indicate whether you prefer option A or option B. There will be a total of 10 lines in the table but just one line will be randomly selected for payment. You do not know which line will be paid when you make your choices. Hence you should pay attention to the choice you make in every line.

After you have completed all your choices, the computer will randomly generate a number, which determines which line is going to be paid out.

Your earnings for the selected line depend on which option you chose: If you chose option A in that line, you will receive 20 ECU. If you chose option B in that line, you will receive either 60 ECU or 0. To determine your earnings in the case you chose option B, there will be a second random draw. The computer will randomly determine if your payoff is 0 or 60, with the chances set by the computer as they are stated in Option B.

Your earning from Stage 2 will be added to your final earnings from this experiment when the experiment is completed.

For the amount of ECU you earned in Stage 2 and in Stage 3 (which we will describe shortly), the conversion rate used is,

10 ECU = $ 1

Stage 3

This stage consists of answering ten (10) quantitative questions. You will be compensated in the following way. For each correct answer you will receive 5 ECU. If you get a question wrong or leave a question unanswered (blank) you will receive 0 ECU, so there is no deduction of points when you make a mistake or leave a question unanswered.

The total amount of time given to you to answer these 10 questions is 8 minutes. Your earning from Stage 3 will be added to your final earnings from this experiment when the experiment is completed. Please remember to submit your answers before the time allocated runs out, otherwise your answers will not be recorded.

Stage 4

In this final stage of the experiment, we will ask you to answer some questions about yourself. Please answer truthfully. When you are finished, we will prepare your earnings, and ask you to sign a receipt, and the experiment will be over.

Thank you again for your participation! If you have any questions, please raise your hand and an experimenter will come to you.

Appendix C Additional Tables of Robustness Checks

Table C1: Conditional Means of Bids and Probability of Entry: Panel-Data Specifications

	All 30 Periods		Final 10 Periods	
	(1) Bid if Enter	(2) Pr(Entry)	(3) Bid if Enter	(4) Pr(Entry)
Zero Entry Fee	60.316	0.909	54.534	0.944
	(2.421)	(0.010)	(2.889)	(0.010)
Optimal Entry Fee	94.607	0.743	87.863	0.740
	(2.444)	(0.017)	(2.967)	(0.020)
High Entry Fee	80.381	0.600	76.518	0.582
	(2.465)	(0.019)	(3.012)	(0.023)

Notes: This table presents an alternative specification for Table 5, specifically a random-effects linear panel-data regression of bids for entering bidders and random-effects Probit panel-data regression of entry probabilities. See the notes to Table 5 for details. The full regression specifications are shown in Table C2.

Table C2: Individual-Level Regression Results for Bids and Entry: Panel-Data Specifications

	All 30 Periods		Final 10 Periods	
	(1) Bid if Enter	(2) Pr(Entry)	(3) Bid if Enter	(4) Pr(Entry)
Optimal Entry Fee	28.970	-0.179	28.075	-0.223
	(3.527)***	(0.020)***	(4.247)***	(0.023)***
High Entry Fee	9.800	-0.301	12.850	-0.357
	(3.630)***	(0.022)***	(4.395)***	(0.025)***
Marginal Cost	-98.154	-0.482	-106.065	-0.473
	(1.414)***	(0.016)***	(2.264)***	(0.022)***
Period	-0.633	-0.000	-0.032	0.003
	(0.042)***	(0.000)	(0.196)	(0.002)*
Probability Test Score	-5.143	-0.141	0.740	-0.159
	(7.239)	(0.051)***	(8.792)	(0.062)***
Past Experiments	-14.388	-0.067	-17.938	-0.059
	(3.957)***	(0.023)***	(4.770)***	(0.028)**
Had Game Theory	-7.730	0.023	-5.154	-0.006
	(3.304)**	(0.020)	(3.992)	(0.025)
Risk Averse Subject	-0.985	-0.028	0.938	-0.062
	(2.959)	(0.018)	(3.574)	(0.022)***
Subject's Age	2.080	0.010	2.914	0.004
	(1.024)**	(0.006)	(1.239)**	(0.008)
Engineering Student	-7.479	0.068	-2.352	0.077
	(4.362)*	(0.026)***	(5.277)	(0.031)**
Science Student	-13.572	0.030	-8.632	0.056
	(4.483)***	(0.027)	(5.417)	(0.032)*
Business Student	-4.510	0.038	-3.925	0.052
	(4.442)	(0.026)	(5.385)	(0.030)*
Female Subject	7.086	0.034	4.810	0.008
	(3.324)**	(0.021)	(4.015)	(0.025)
N	8097	10800	2712	3600
Log Likelihood	-40,155.462	-3,855.962	-13,352.339	-1,156.011

Notes: This table presents an alternative specification for Table 6, specifically a panel-data random-effects linear regression of bids for entering bidders and panel-data random-effects Probit regression of entry probabilities. See the notes to Table 6 for details.

Appendix D Additional Experimental Results

In addition to the experimental sessions reported in the text, we conducted additional experiments that serve as robustness checks. These additional sessions differ from the main sessions in that they used different parameters for the cost distribution. Specifically, we use two different cost distributions: $[\underline{c}, \overline{c}] = [1, 2]$ and $[\underline{c}, \overline{c}] = [1, 3]$. Using the parameters from the main experiment and the parameters from the robustness checks, we denote the cost distribution by the upper bound (i.e., 1.5, 2, and 3). The following expressions provide the entry threshold above which no contestant is predicted to enter ($\widehat{c}$), the equilibrium bidding function ($b(c; \widehat{c})$), and the optimal entry fee (E^*) that maximizes total effort.

$$\begin{aligned}
\widehat{c}_{1.5} &= \frac{300 + E}{200 + 2E}, \\
\widehat{c}_2 &= \frac{200 + E}{100 + E}, \\
\widehat{c}_3 &= \frac{300 + E}{100 + E}.
\end{aligned}$$

$$\begin{aligned}
b(c; \widehat{c}_{1.5}) &= (100 + 2E)\left[\ln\left(\frac{300 + E}{200 + 2E}\right) - \ln c\right], \ \forall c \leq \widehat{c}_{1.5}, \\
b(c; \widehat{c}_2) &= (100 + 2E)\left[\ln\left(\frac{200 + E}{100 + E}\right) - \ln c\right], \ \forall c \leq \widehat{c}_2, \\
b(c; \widehat{c}_3) &= (50 + E)\left[\ln\left(\frac{300 + E}{100 + E}\right) - \ln c\right], \ \forall c \leq \widehat{c}_3.
\end{aligned}$$

$$\begin{aligned}
E^*_{1.5} &= 40.393, \\
E^*_2 &= 24.170, \\
E^*_3 &= 40.393.
\end{aligned}$$

These additional sessions had an additional 144 subjects and no subject participated in more than one session. These additional sessions also used a different payment scheme than that described in the main text, specifically a two-part exchange rate that paid subjects S\$ 1 for every 150 ECU up to 1000 ECU and S\$ 1 for every 25 ECU above 1000 ECU. This two-part exchange rate was designed to incentivize subjects to participate in the contest rather than to sit out and simply earn 1000 ECU. These additional sessions are summarized in Table D1.

Table D1: Summary of Additional Treatments

	Zero Entry Fee ($E = 0$)	Optimal Entry Fee ($E = E^*$)	High Entry Fee ($E = 3E^*$)
$[\underline{c}, \overline{c}] = [1, 2]$	1 Session	1 Session	1 Session
	$E = 0$	$E = 24.1704$	$E = 72.5112$
	$\widehat{c} = 2$	$\widehat{c} = 1.8053$	$\widehat{c} = 1.5797$
	$TE = 61.3706$	$TE = 63.6658$	$TE = 60.0084$
$[\underline{c}, \overline{c}] = [1, 3]$	1 Session	1 Session	1 Session
	$E = 0$	$E = 40.3925$	$E = 121.1775$
	$\widehat{c} = 3$	$\widehat{c} = 2.4246$	$\widehat{c} = 1.9043$
	$TE = 45.0694$	$TE = 48.7144$	$TE = 44.5340$

Notes: Shown is the design of the treatments in the additional sessions. See the notes to Table 1 for definitions.

The results in these additional sessions confirm the findings presented in the main text. Table D2 shows the total effort expended by both contestants, which is equivalent to the revenue earned by the principal in each treatment. These treatment-level means are shown for each cost distribution (costs distributed on $[1, 2]$ in Panel A and $[1, 3]$ in Panel B) and for each level of the entry fee. We are not primarily interested in variation in the bounds of the cost distribution per se; this treatment variation is a useful check on the robustness of the comparisons we make along our key dimension of treatment variation, which is the level of the entry fee.

On average, the optimal entry fee induces more total effort than either no entry fee or an entry fee that is three times larger than the optimal entry fee. The advantage of the optimal entry fee in percentage terms is 13.21% and 13.52% more total effort with respect to no entry fee for distributions $[1, 2]$ and $[1, 3]$, respectively. The advantage with respect to the high entry fee is 35.10% and 49.18% for distributions $[1, 2]$ and $[1, 3]$, respectively. These large gains in total effort strongly support the results presented in the main text.

As in the main text, we present the total effort distributions between treatments. Figures D1 and D2 present empirical CDFs of total effort as the entry fee varies for the two additional cost bounds, $[1, 2]$ and $[1, 3]$, respectively. The optimal entry fee generates an empirical CDF of total effort that is clearly shifted right relative to either a zero or high entry fee.

Next, Figures D3 and D4 illustrate the bidding functions derived from our experimental data.

Table D2: Summary Statistics for Total Effort, Bids, and Efficiency

Panel A: $[\underline{c}, \overline{c}] = [1, 2]$			
	(1) Total Effort	(2) Bid if Enter	(3) Efficiency
Zero Entry Fee	94.848	49.136	0.594
	(3.166)	(1.550)	(0.027)
Optimal Entry Fee	107.375	65.606	0.677
	(3.350)	(1.547)	(0.027)
High Entry Fee	79.479	62.005	0.670
	(3.249)	(1.904)	(0.026)
N	960	1551	960

Panel B: $[\underline{c}, \overline{c}] = [1, 3]$			
	(1) Total Effort	(2) Bid if Enter	(3) Efficiency
Zero Entry Fee	73.459	40.742	0.715
	(2.309)	(1.211)	(0.025)
Optimal Entry Fee	83.392	53.419	0.663
	(2.224)	(1.057)	(0.020)
High Entry Fee	55.900	39.586	0.779
	(2.040)	(0.985)	(0.023)
N	1200	1904	1200

Notes: Panel A shows treatments in which marginal bidding costs were distributed on $[1, 2]$ and Panel B shows treatments with costs on $[1, 3]$. See the notes to Table 2 for details.

They are remarkably consistent with the theoretical bidding functions shown in Figure 1 and with the results discussed for the main treatments in the text.

Finally, the other columns in Table D2 and Table D3 present the remaining variables of interest, repeating the summary statistics tables from the main text. The qualitative patterns in these additional sessions are quite similar to the main treatments.

In these robustness checks, the optimal entry fee raises revenue by at least 13.21% relative to no entry fee and at least 35.10% relative to an entry fee that is set too high.

Table D3: Summary Statistics for Entry

Panel A: $[\underline{c}, \bar{c}] = [1, 2]$				
	(1) Number of Entrants	(2) Excess Entrants	(3) Entry Rate: High Types	(4) Entry Rate: Low Types
Zero Entry Fee	1.930	-0.070	0.965	
	(0.015)	(0.015)	(0.007)	
Optimal Entry Fee	1.637	0.017	0.885	0.580
	(0.031)	(0.037)	(0.016)	(0.059)
High Entry Fee	1.282	0.197	0.771	0.430
	(0.036)	(0.043)	(0.028)	(0.034)
N	960	960	740	220

Panel B: $[\underline{c}, \bar{c}] = [1, 3]$				
	(1) Number of Entrants	(2) Excess Entrants	(3) Entry Rate: High Types	(4) Entry Rate: Low Types
Zero Entry Fee	1.803	-0.197	0.902	
	(0.023)	(0.023)	(0.012)	
Optimal Entry Fee	1.561	0.107	0.846	0.542
	(0.026)	(0.033)	(0.015)	(0.040)
High Entry Fee	1.412	0.512	0.928	0.494
	(0.036)	(0.039)	(0.019)	(0.032)
N	1200	1200	880	320

Notes: Panel A shows treatments in which marginal bidding costs were distributed on $[1, 2]$ and Panel B shows treatments with costs on $[1, 3]$. See the notes to Table 3 for details.

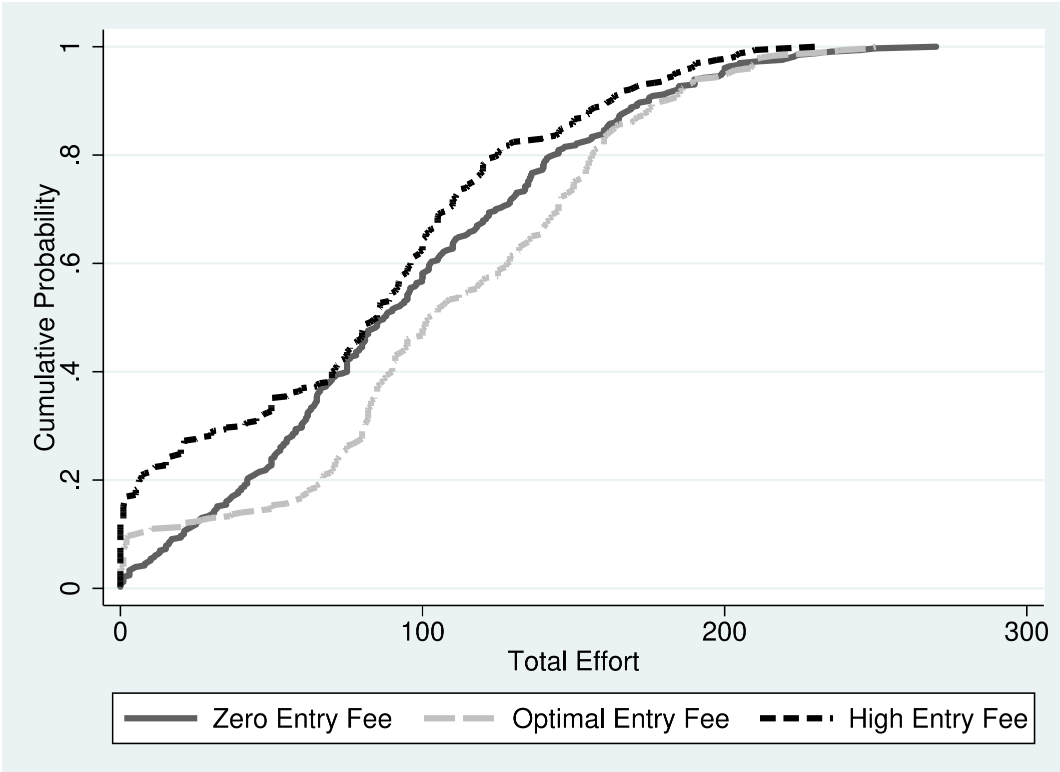

Figure D1: CDFs of Total Effort, [1,2] Treatments, All 30 Periods

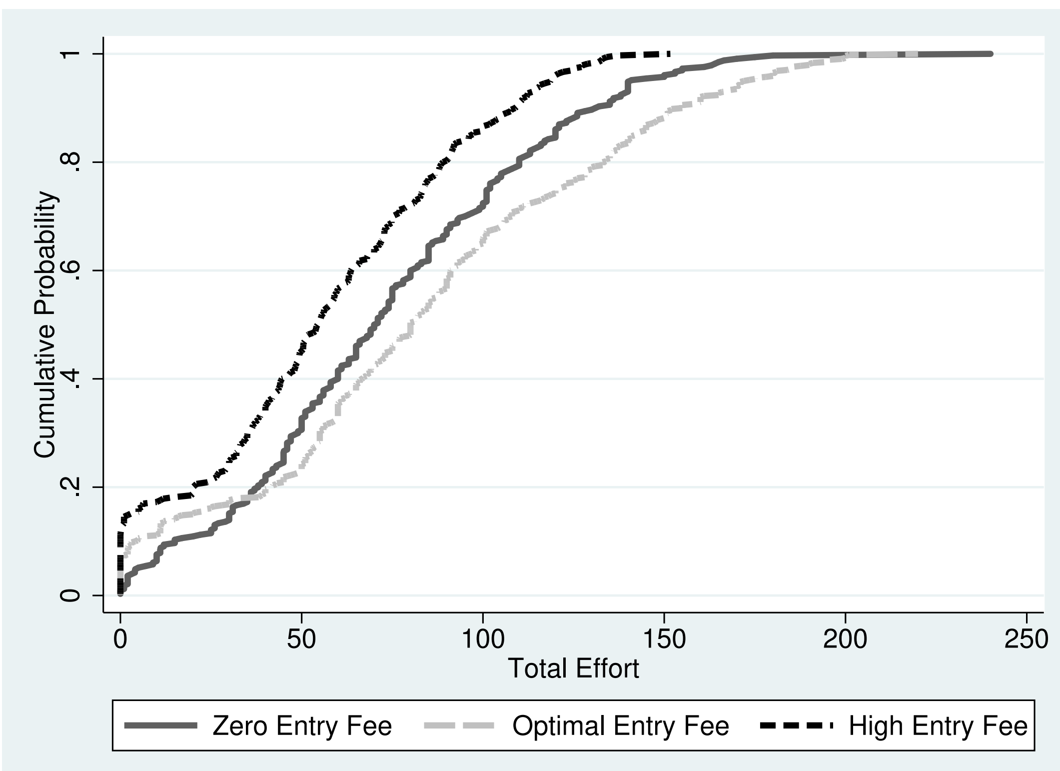

Figure D2: CDFs of Total Effort, [1,3] Treatments, All 30 Periods

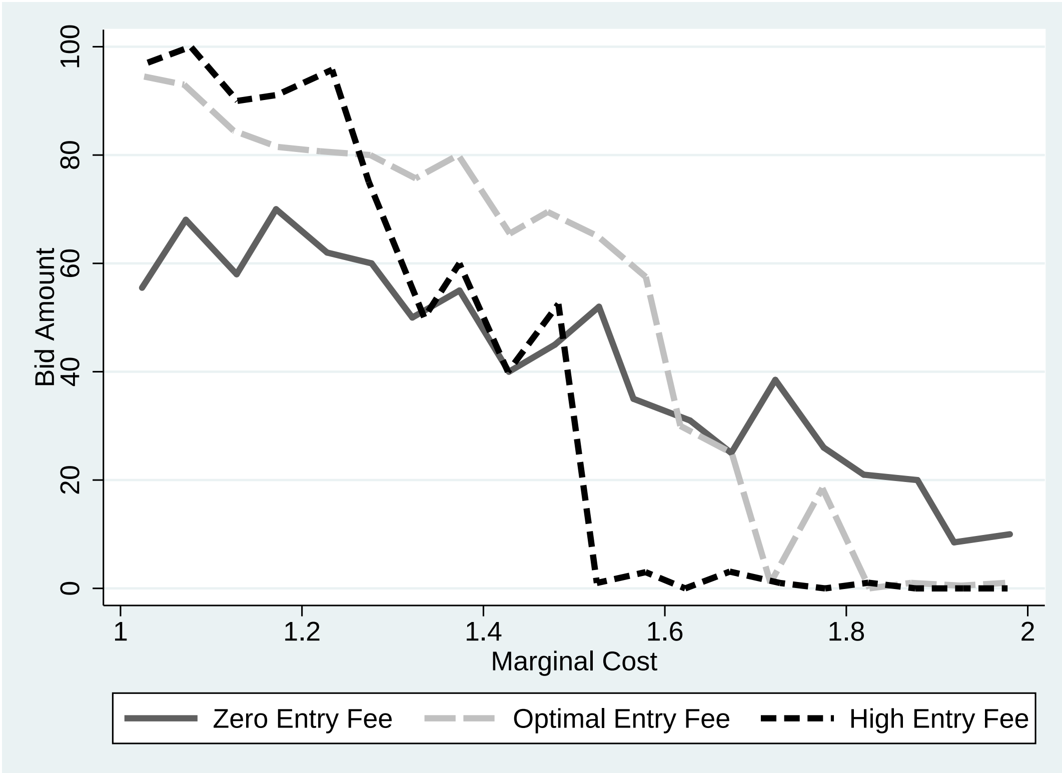

Figure D3: Average Bids of Entering Bidders, [1,2] Treatments, All 30 Periods

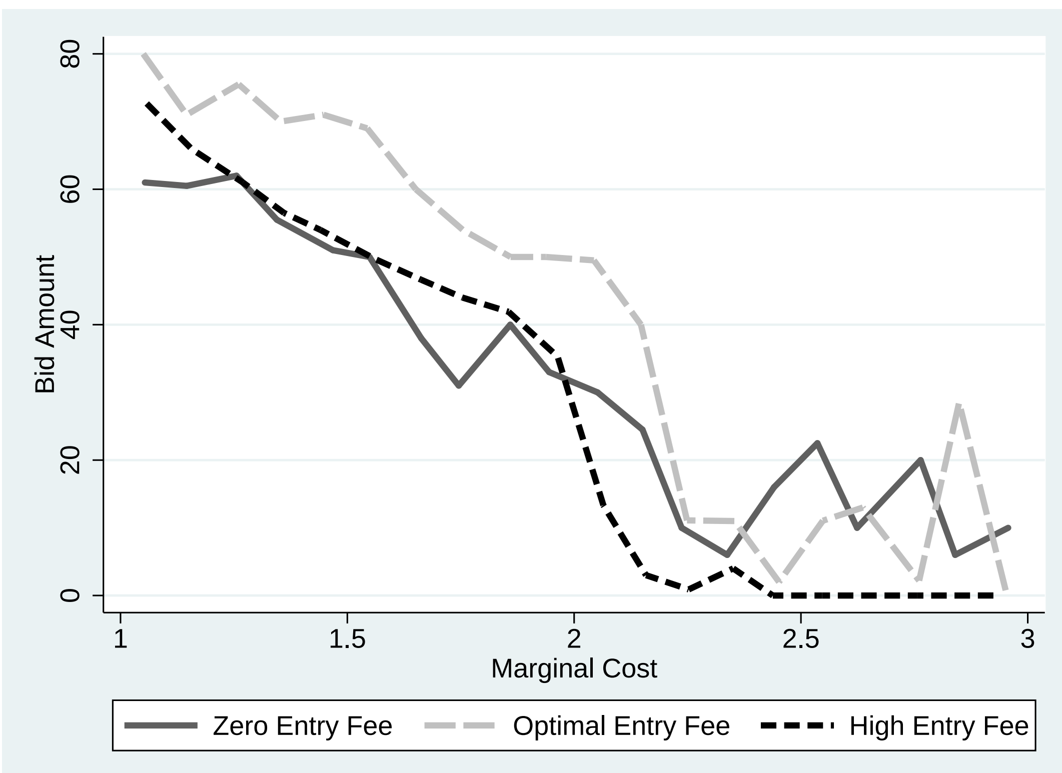

Figure D4: Average Bids of Entering Bidders, [1,3] Treatments, All 30 Periods