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A Survey of Experimental Research on Contests, All-Pay Auctions and Tournaments

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Abstract

Many economic, political and social environments can be described as contests in which agents exert costly efforts while competing over the distribution of a scarce resource. These environments have been studied using Tullock contests, all-pay auctions and rank-order tournaments. This survey provides a comprehensive review of experimental research on these three canonical contests. First, we review studies investigating the basic structure of contests, including the number of players and prizes, spillovers and externalities, heterogeneity, risk and incomplete information. Second, we discuss dynamic contests and multi-battle contests. Then we review studies examining sabotage, feedback, bias, collusion, alliances, group contests and gender, as well as field experiments. Finally, we discuss applications of contests and suggest directions for future research.

JEL Classifications: C7, C9, D7, H4, J4, J7, K4, L2, M5
Keywords: contests, all-pay auctions, tournaments, experiments.

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1. Introduction

Many economic, political and social environments can be described as contests in which competing agents have the opportunity to expend scarce resources – such as effort, money, time, or troops – in order to affect the probabilities of winning prizes. Examples range from the competition for mates, college admission, patents, or promotions within firms, to the process of litigation or lobbying politicians, to elections, sports competitions, and violent global conflicts (Tullock, 1967; Krueger, 1974). As is obvious from this list, these environments have attracted considerable attention in applications in a wide range of fields, both in- and out-side of economics. They have also been studied extensively by economic theorists in what has become known as the field of contest theory (Konrad, 2009). Although this field continues to attract many young theorists, it has its roots in three models developed in the mid-seventies to early eighties: the Tullock (1980) model of rent-seeking, the Lazear and Rosen (1981) rank-order tournament model, and the all-pay auction (Hirshleifer and Riley, 1978; Nalebuff and Stiglitz, 1983; Dasgupta, 1986; Hillman and Riley, 1989). Despite the fact that the three models historically developed somewhat independently, they represent special cases of a general contest model that can be formulated in a unified framework.

Despite an extensive and established theoretical literature, much less effort has been devoted to empirically investigate individual behavior in different contests and compare such behavior with theoretical predictions. The main reason is that it is not trivial to measure individual effort in the field since the researcher can only observe the performance of contestants, which is a function of effort, ability and luck (Ericsson and Charness, 1994). The majority of empirical studies use either firm level data (Prendergast, 1999) or sports data (Szymanski, 2003). Because it is typically difficult to measure the actual effort expended by players in the field, almost all of these studies focus solely on investigating whether the pattern of outcomes is consistent with the theoretical predictions.

Controlled experiments allow researchers to test contest theory without confounding effects and endogeneity issues. Some experiments allow direct measurement of individual effort, while controlling for the relative abilities of contestants and the amount of noise (luck) in the tournament. The first studies to test contest theory using laboratory methods were conducted by Bull et al. (1987) and Millner and Pratt (1989). These studies have inspired a substantial and rapidly developing experimental literature on contests. The purpose of this paper is to survey this work. We begin by identifying the three canonical contest models and their common applications.

The assumptions underlying the three contest models lead to vastly different equilibrium behaviors. Tullock (or lottery) contests and rank-order tournaments usually have pure strategy equilibria for the specifications applied, whereas all-pay auctions have only non-degenerate mixed strategy equilibria (in the case of complete information). Moreover, the models have traditionally been applied to different areas of economic analysis. The term *Tullock* or *lottery contest* has been commonly used in the study of R&D races and political or rent-seeking competitions. *Rank-order tournaments* (or sometimes *tournaments*) have been used in the principal-agent, contract design and labor literatures. Therefore, resources exerted in the process of competing in these contests are usually called efforts or expenditures. *All-pay auctions* have been used in the auction literature and in lobbying and military applications. Resources exerted competing in all-pay auctions are usually called bids or expenditures.

In any given application, contest expenditures may be viewed as a good or bad from the standpoint of the contest designer. For instance, when modeling political or rent-seeking competition, contest expenditure is often viewed as social waste, in the sense that a welfare maximizing social-planner would seek to minimize it (Tullock, 1980). In contrast, in management applications where rank-order tournaments have often been applied, effort is viewed as valuable because it contributes to the firm's output. Similarly, for patent races a social planner may desire the positive externalities generated from increases in R&D spending. Finally, in many all-pay auction applications expenditure is viewed as desirable, such as the case of charitable fundraising or a seller of an object engaging in an all-pay auction to maximize revenue. Consequently, in some applications of contests the designer may be interested in maximizing expenditure and in some cases minimizing expenditure. Although applications of the three canonical models are usually different, all three models assume that (i) players exert costly irreversible efforts while competing for a prize and (ii) an individual player's probability of winning the prize depends on the players' relative expenditures. Obviously, the exact probability of winning the prize is defined differently for the three contests and is determined by a contest success function that maps the vector of player expenditures to the probability of winning. In the *all-pay auction*, the player exerting the highest effort wins the prize with certainty. In the *rank-order tournament*, the player with the highest performance, which is the sum of effort and a random component, wins the prize with certainty. Finally, in the *Tullock contest*, the probability of winning equals the ratio of a player's effort to a fixed power $r \geq 0$ to the sum of each of the other players' efforts, each raised to the same power r. The special case where $r = 1$ is the case of the lottery contest.

We survey 231 experimental papers on contests; for a complete list of references see the working version of this paper (Dechenaux et al., 2012).[1] The majority of these papers are already published or in press (159 papers), while other papers are still cited as working papers (72 papers). More than 90% of the working papers have been written within the last five years. Figure 1 displays the time trend of papers published in academic journals. The figure indicates a dramatic increase in the number of published papers over the last decade, with more than 50% of the papers published in the last five years. The vast majority of published experimental studies are conducted in the lab (87%) employing chosen-effort experiments (75%). Some experimental studies are conducted in the field (13%), with more than 70% of the field studies published within the last five years. Out of 158 published papers, 35% of the papers are based on lottery contests, 25% are based on all-pay auctions, 25% on rank-order tournaments and about 15% of the studies examine other contest structures (usually using binary decisions or real-effort tasks).

We begin by introducing the three canonical contest models in Section 2. There are four important lessons that we learn from studies discussed in Section 2: (1) most studies on lottery contests and all-pay auctions find significant overbidding relative to the Nash equilibrium prediction; (2) in contrast to lottery contests and all-pay auctions, there is little overbidding in rank-order tournaments and aggregate effort usually conforms to the theoretical predictions; (3) in all three canonical contests there is significant heterogeneity in the behavior of individual subjects; (4) in lottery contests and rank-order tournaments bids are usually distributed around the equilibrium, while in all-pay auctions the distribution of bids is bimodal, with some subjects submitting very low and others submitting very high bids.

[1] Our survey is comprehensive, so we tried to include all of the available experimental papers on contests which were available in 2012. We used Google Scholar, RePEc, and SSRN to locate most of the published as well as working papers. Then, we sent an e-mail to the ESA Google Group requesting additional working papers that we could not locate in our original search.

In Section 3 we present experimental studies investigating the basic structure of contests, including the number of players and prizes, spillovers and externalities, heterogeneity, risk and incomplete information. The main lesson that we learn from the experiments discussed in Section 3 is that most studies find support for the comparative statics predictions of contest theory. Some commonly supported comparative statics results are the impact of incomplete information on individual behavior, the "discouragement effect", and the impact of contest parameters (e.g., the number of players and the number of prizes) on effort.

Then we identify some common areas of focus within the literature and present a general review of relevant studies. For example, Section 4 reviews contests with a dynamic structure, such as sequential move contests, wars of attrition, multi-stage contests, patent races, best-of-n contests, multi-stage elimination contests, and contests with endogenous entry. Section 5 reviews experimental studies on games of multiple contests with linkages, such as Colonel Blotto games and multi-battle contests. Section 6 presents natural extensions of the experimental analysis of contests, such as sabotage, feedback, bias, collusion, alliances, group contests, and gender effects. Section 7 reviews field experiments on contests. Section 8 discusses a number of applications of contests, including litigation, political campaigning, lobbying, wars, sales, and charity giving.

Finally, Section 9 suggests several directions for future research, including an examination of (1) the sources of overbidding in lottery contests and all-pay auctions, (2) the reasons for little (or no) overbidding in rank-order tournaments, (3) potential overbridging in field settings with real-effort and high stakes, and (4) potential mechanisms of de-escalation, deterrence, management and resolution of conflicts.

2. Three Canonical Contest Models

A contest is a game in which players are able to expend scarce resources (such as money, time or effort) in order to affect the probabilities of winning prizes, the values of which are ranked identically by the players (but may not be identical in absolute terms). The distinguishing characteristic of a contest is the fact that a higher expenditure of the scarce resource(s) has a nonnegative (and sometimes strictly positive) effect on the probability of winning the more valuable prizes.

There is a wide variety of possible contests that meet the above conditions, but our focus throughout this survey will be, respectively, on (i) the Tullock contest, (ii) the all-pay auction and (iii) the rank-order tournament. In this section, we provide a simple theoretical overview of all three models in the context of a one-shot simultaneous-move contest of complete information between homogeneous players.

Assume there are n risk-neutral players competing for a single prize with common value v. Each player i expends an effort e_i and bears a cost of effort $c(e_i)$. The performance or output of player i, y_i, depends on player i's effort e_i and a random variable ε_i, independently drawn from some common distribution with cumulative distribution function F:

$$y_i(e_i, \varepsilon_i) = e_i + \varepsilon_i. \qquad (1)$$

The additive random component ε_i, can be thought of as unobservable luck or performance error. It can also be interpreted as an unknown ability ε_i (Rosen, 1986).

Player i's probability of winning the contest as a function of the observable n-tuple of outputs $y = (y_1, y_2, \dots, y_n) \geq 0$ is given by

$$\hat{p}_i(y_i, y_{-i}) = \frac{y_i^r}{\sum_{j=1}^n y_j^r}, \tag{2}$$

if $\sum_{j=1}^n y_j > 0$ and $\hat{p}_i(y_i, y_{-i}) = \frac{1}{n}$ otherwise, where $r \geq 0$ is a parameter that measures the sensitivity of the probability of winning to the ratio of individual player outputs. In practice, for the appropriate measure of the outputs, $\hat{p}_i(y_i, y_{-i})$ may be estimated because it is based purely on the observable player outputs, rather than the potentially unobservable allocations of the scarce resource. The random mapping that compounds (1) and (2) to take a vector of player efforts $e = (e_1, e_2, \dots, e_n)$ and obtain the probability that each player i wins the contest is called the contest success function (CSF): $p_i(e_i, e_{-i})$.

The outcome-contingent payoff of player i in the contest is

$$\pi_i = \begin{cases} v - c(e_i) & \text{if } i \text{ wins} \\ v/n - c(e_i) & \text{if } i \text{ ties} \\ -c(e_i) & \text{if } i \text{ loses} \end{cases}. \tag{3}$$

Given the performance function (1), the CSF induced by (1) and (2), and the outcome-contingent payoff function (3), the expected payoff for player i can be written as:

$$E(\pi_i) = p_i(e_i, e_{-i})v - c(e_i). \tag{4}$$

A simple version of a *Tullock contest* can be obtained by setting $y_i = e_i$ in (1), $r \geq 0$ in (2), and $c(e_i) = e_i$ in (3). One may interpret such a contest as a case in which there is no noise in the performance function (1), so $\varepsilon_i = 0$, but where the CSF coincides with (2), so that the probability of winning the prize equals the ratio of individual effort to aggregate effort and individual output to aggregate output. When r is relatively small (a sufficiently noisy CSF) and there are no externalities of effort, the Nash equilibrium in a simple Tullock contest is in pure strategies and it is unique. The case where $r = 1$ is referred to as the *lottery contest*. The equilibrium is not in pure strategies when r is relatively large (Baye et al., 1994), and it is not unique when there are externalities of effort (Chowdhury and Sheremeta, 2011b). In the remainder of the paper we refer to contests where $0 \leq r < \infty$ and $y_i = e_i$ as *Tullock contests*.

To obtain a simple version of the *all-pay auction*, we set $y_i = e_i$ in (1), $r = \infty$ in (2), and $c(e_i) = e_i$ in (3). The crucial difference when compared to the Tullock contest is that, except in the event of ties, the outcome is deterministic; the player with higher effort wins the contest with certainty. There is no pure strategy equilibrium in the all-pay auction. Only non-degenerate mixed strategy Nash equilibria exist in which players choose efforts randomly over the interval $[0, v]$ (Hillman and Riley, 1989; Baye et al., 1996).

Finally, to obtain a simple *rank-order tournament* we set $y_i = e_i + \varepsilon_i$ in (1), $r = \infty$ in (2), and $c(e_i) = c(e)$ in (3), where $c_e > 0$ and $c_{ee} > 0$. The crucial difference between the rank-order tournament and the Tullock contest and the all-pay auction is that in the former there is a noise component ε_i in the performance function (3), i.e., $y_i = e_i + \varepsilon_i$. As in Tullock (1980), the rank-order tournament is often formulated in a way that generates a unique pure strategy Nash equilibrium. This occurs if there is a sufficient combination of noise and convexity of cost

(Lazear and Rosen, 1981). In the rest of the paper we will refer to contests where $r = \infty$ and $y_i = e_i + \varepsilon_i$ as *Lazear-Rosen* or *rank-order tournaments*.

2.1. Tullock or Lottery Contests

The first attempt to examine a lottery contest using laboratory methods dates back to Millner and Pratt (1989). Their experiment was based on the original Tullock (1980) model with r = 1 and r = 3. Subjects were placed in groups of two and the composition of the groups changed from period to period. However, instead of using a design in which the subjects make simultaneous single decisions, the subjects were allowed to adjust their decisions during a continuous time interval. For the benchmark lottery case of r = 1 the two main findings of Millner and Pratt (1989) are that (i) the average dissipation rate (measured as the total effort divided by the prize value) in the lottery contest is significantly higher than the risk-neutral equilibrium prediction and (ii) there is a large variation in individual effort levels.

Since Millner and Pratt (1989), many other experiments on lottery contests (e.g., Davis and Reilly, 1998; Potters et al., 1998; Anderson and Stafford, 2003; Sheremeta, 2010a, 2010b, 2011a; Sheremeta and Zhang, 2010; Savikhin and Sheremeta, 2012; Morgan et al., 2012) have replicated (i) overbidding (which we also refer to as over-expenditure of effort) and (ii) heterogeneous behavior of ex-ante symmetric contestants. Figure 2 displays a distribution of effort commonly observed in lottery contests. The data are taken from Sheremeta (2011a), where n = 2 players compete for a prize of v = 60 in a lottery contest (i.e., $r = 1$, $y_i = e_i$, and $c(e_i) = e_i$). According to the theoretical prediction, the Nash equilibrium effort is $e^* = v(n-1)/n^2$ = 15. Nevertheless, average efforts are significantly higher than predicted and the variance is substantial.

There are different explanations that have been proposed in the literature for overbidding (Sheremeta, 2013, 2014). The first is that, in addition to monetary incentives, subjects derive a non-monetary utility from winning (Schmitt et al., 2004; Parco et al., 2005; Sheremeta, 2010a, 2010b; Price and Sheremeta, 2011, 2014; Brookins and Ryvkin, 2014; Mago et al., 2014). Sheremeta (2010b) illustrates subjects' non-monetary utility of winning in an example of a simple lottery contest with a prize value of zero (i.e., v = 0). Interestingly, about 40% of the subjects exert positive costly effort in contests for a prize of v = 0 and these efforts are correlated with efforts in contests for a strictly positive prize of v = 120. Figure 3 displays the correlation between effort for a prize of v = 0 and effort for a prize of v = 120. The data are taken from Sheremeta (2010b), where n = 4 players compete in a lottery contest. According to the theoretical prediction, when v = 120, the Nash equilibrium effort is $e^* = v(n-1)/n^2$ = 22.5. Figure 3 shows that subjects who exert higher efforts for the prize of zero also exert higher efforts for the positive monetary prize of 120 (correlation coefficient of 0.38).[2]

The second reason for overbidding is that, in addition to the utility from winning, subjects care about their relative payoffs (Herrmann and Orzen, 2008; Mago et al., 2014). Using a modified utility function, Mago et al. (2014) prove theoretically that status-seeking subjects who strive to maximize their relative payoffs should exert higher efforts in equilibrium. In their experiment, Mago et al. (2014) find that 51% of subjects indicate positive utility from winning

[2] Whether this correlation comes from non-pecuniary benefits from winning or other sources demands further research. For instance, it may be the case that subjects who make errors in assessing their bidding strategies for a prize of value zero also are likely to make errors in bidding for higher value prizes. At the same time, it may well be the case that the non-pecuniary benefits from winning are not invariant to the monetary value of the prize.

and 67% of subjects behave as status-seekers, suggesting that overbidding in contests can be explained by a combination of a utility from winning and relative payoff maximization.

The third explanation is based on the fact that subjects are prone to mistakes. These mistakes add noise to the Nash equilibrium solution, and thus may cause overbidding in contests. Several studies have provided support for this argument by analyzing the quantal response equilibrium model (McKelvey and Palfrey, 1995), which accounts for errors made by subjects, and testing the predictions of this model in lottery contests (Sheremeta, 2011a; Chowdhury et al., 2014; Lim et al., 2014).

A fourth explanation suggests that overbidding in contests can also be explained by the fact that subjects exhibit certain judgmental biases, such as non-linear probability weighting and the hot hand fallacy, which prevent them from exerting rational effort levels in contests (Parco et al., 2005; Amaldoss and Rapoport, 2009; Sheremeta and Zhang, 2010).

Finally, several recent studies suggested that a significant amount of non-equilibrium behavior in contests can be explained by features of the experimental design (Fallucchi et al., 2013; Chowdhury et al., 2014; Masiliunas et al., 2014). For example, in a two-by-two design, Chowdhury et al. (2014) vary whether the prize is assigned probabilistically (i.e., efforts determine the probabilities of winning the prize) or proportionally (i.e., efforts determine the shares of the prize) and whether the cost function is linear or convex, while holding the Nash equilibrium effort level constant. They find that compared to the probabilistic CSF, the proportional rule results in average effort closer to the Nash prediction. Combining the share rule with a convex cost function further enhances this result.

Heterogeneous behavior of ex-ante symmetric contestants is usually attributed to demographic differences, heterogeneous preferences towards winning, risk, losses and inequality (Sheremeta, 2013, 2014). Price and Sheremeta (2014), for example, find that men and more religious subjects tend to exert up to 25% lower effort than women and less religious subjects. Sheremeta (2010a, 2010b) finds that subjects who demonstrate having higher non-monetary utility of winning exert higher effort in lottery contests (see Figure 3). Many studies find that risk-averse subjects exert lower efforts in lottery contests than risk-neutral or risk-seeking subjects (Millner and Pratt, 1991; Anderson and Freeborn, 2010; Sheremeta and Zhang, 2010; Sheremeta, 2011a; Shupp et al., 2013; Mago et al., 2013). Shupp et al. (2013) find that more loss-averse subjects exert lower efforts than less loss-averse subjects. Finally, Mago et al. (2014) find that inequality-averse subjects exert higher efforts than subjects who care only about their own payoffs.

2.2. All-Pay Auctions

In this section we discuss the contest known as an all-pay auction with complete information (Hillman and Riley, 1989; Baye et al., 1996).[3] In such a contest the highest bidder wins the prize with certainty and all bidders have to pay their bids. Baye et al. (1996) characterize the entire set of equilibria for the all-pay auction with complete information, a continuous strategy space and arbitrary prize valuations. All equilibria are in mixed strategies and in games with three or more players, for certain configurations of the players' valuations of the prize, multiple equilibria exist. One feature of Nash equilibrium is that it may be asymmetric even in symmetric games.

[3] Early treatments of special cases of all-pay auctions include Hirshleifer and Riley (1978), Nalebuff and Stiglitz (1983) and Dasgupta (1986).

As in Tullock contests, overbidding relative to the Nash equilibrium prediction in aggregate data emerges as an empirical regularity. Davis and Reilly (1998) were arguably the first to report substantial overbidding in all-pay auctions using a design that focused on asymmetric auctions. Their important finding carries over to symmetric all-pay auctions. Indeed, except for Potters et al. (1998), the majority of studies using symmetric all-pay auctions with complete information also find that session averages reflect overbidding (Gneezy and Smorodinsky, 2006; Lugovskyy et al., 2010; Fehr and Schmidt, 2011; Klose and Sheremeta, 2012; Ernst and Thöni, 2013; Ong and Chen, 2013). While Potters et al. find evidence of equilibrium play in their two-player all-pay auction experiment, their design imposed an exogenous cap on bids (15% above the prize value), which may have biased behavior toward lower, equilibrium bids. In contrast, a study by Gneezy and Smorodinsky (2006) finds that the sum of effort levels (or "revenue", in the language of auction theory) is much higher than predicted and often twice to five times higher than the common prize value. Winning bids are frequently within 10 percentage points of the value of the prize and sometimes exceed it. Moreover, Gneezy and Smorodinsky (2006) find that subjects appear to randomize over a set of bids as theory predicts, but they tend to place too much weight on relatively low and relatively high bids. Figure 4 displays a distribution of bids in one of the treatments from Gneezy and Smorodinsky (2006). In this treatment, there are $n = 4$ players competing for a prize of $v = 100$ in an all-pay auction (i.e., $r = \infty$, $y_i = e_i$, and $c(e_i) = e_i$). The picture shows clear evidence of *bimodal* behavior, with some subjects submitting very low and others submitting very high bids.[4] Many other all-pay auction studies generate distributions with a similar shape. Klose and Sheremeta (2012) and Ernst and Thöni (2013) rely on loss aversion from Kahneman and Tversky's (1979) prospect theory to explain bimodal behavior. The basic assumption is that players evaluate outcomes relative to a reference point. If they earn more than their reference point, they are in the domain of gains, otherwise in the domain of losses. The utility function is concave in the domain of gains and convex in the domain of losses. In addition, people suffer more from the loss of a certain amount of money than they enjoy from the win of the same amount. A utility function based on these assumptions gives rise to a bimodal bidding behavior in the equilibrium of an all-pay auction.

Lugovskyy et al. (2010) further explore observed deviations from Nash equilibrium in all-pay auctions. In long sessions, lasting 60 periods, with fixed matching of four-player groups, they show that learning seems to bring bids closer to the Nash equilibrium prediction in the aggregate. Aggregate over-dissipation also decreases in long sessions under random matching, but remains above the levels observed with fixed matching. In their early experimental treatment of an asymmetric all-pay auction, Davis and Reilly (1998) also report that experience reduces overbidding.

While caution is warranted when drawing parallels between the two contest forms, it is natural to ask whether the pattern of overbidding in all-pay auctions arises from the same factors as in lottery contest experiments. For example, as in lottery contests, overbidding in all-pay auctions may be caused by mistakes, a non-monetary utility of winning or judgmental biases. However, further research is required to conclusively determine whether patterns of data in all-pay auctions and lottery contests are caused by the same phenomenon.

[4] In the symmetric complete information all-pay auction with a continuous strategy space and $n = 4$, there is a continuum of asymmetric Nash equilibria in which one or two players place probability mass at 0. Hence, a significant incidence of zero bids may be consistent with behavior in asymmetric equilibria.

2.3. Rank-Order Tournaments

Since the seminal paper by Lazear and Rosen (1981), rank-order tournaments have been extensively investigated in the lab. To the best of our knowledge the first laboratory experiment on rank-order tournaments is Bull et al. (1987). Bull et al. implement rank-order tournaments between pairs of subjects whose output is the sum of effort and a uniformly distributed productivity shock, i.e., $y_i = e_i + \varepsilon_i$ where $\varepsilon_i \sim U[-a, a]$. In their design, a sufficiently disperse support of the distribution of the noise parameter ε_i guarantees that a unique pure strategy Nash equilibrium exists. The main purpose of the experiment was to test the theory and to compare the performance of a rank-order tournament to a simple piece-rate incentive scheme. The main results of Bull et al. (1987) are that the average effort levels in tournaments are well predicted by theory and are similar to efforts under the piece-rate scheme.[5] However, the variance of effort is much greater under the tournament.

The findings of Bull et al. (1987) have been replicated by a large number of experiments on rank-order tournaments (Schotter and Weigelt, 1992; Nalbantian and Schotter, 1997; Harbring and Irlenbusch, 2005, 2008; Orrison et al., 2004; Wu and Roe, 2005; Wu et al. 2006; Harbring et al., 2007; Harbring and Lünser, 2008; Eriksson et al., 2009b; Sheremeta and Wu, 2011; Eisenkopf and Teyssier, 2012, 2013; Agranov and Tergiman, 2013). Several exceptions are Chen et al. (2011), who observe over-expenditure in contests with asymmetric contestants, and Kräkel and Nieken (2012), who observe twice as high effort levels than predicted in a tournament with minimum productivity requirements. Figure 5 displays the dynamics of average effort over the length of the experiment commonly observed in rank-order tournaments. The data are taken from Orrison et al. (2004) where n = 2, 4 or 6 symmetric players compete for large prizes of v_1 = \$2.04 (1, 2 or 3 prizes, respectively) and small prizes of v_2 = \$0.86 (1, 2 or 3 prizes, respectively) in a rank-order tournament (i.e., $r = \infty$, $y_i = e_i + \varepsilon_i$, $\varepsilon_i \sim U[-a, a]$ and $c(e_i) = e_i^2/b$, where a = 60 and b = 15,000). According to the theoretical prediction, the Nash equilibrium effort is $e^* = (v_1 - v_2)b/4a$ = 73.5. As Figure 5 indicates, for every n, the average effort is quite close to the predicted level and there is no overbidding.

Although on average there is little (or no) overbidding in rank-order tournaments, heterogeneity of individual behavior is widespread (Bull et al., 1987). The high variance of effort is especially problematic because in a labor-management context, where rank-order tournaments are often employed in the field (for a review see Charness and Kuhn, 2011), a high variance in individual performance can impose a substantial cost on employers and reduce the overall efficiency of the work place (Lazear, 1999, 2000). What might account for the high variance in individual effort? In their follow-up to Bull et al. (1987), Drago and Heywood (1989) argue that part of the variance in the Bull et al. data may simply be due to relatively flat payoff functions. They conduct several additional treatments and show that the variance in effort is comparable between a tournament and piece-rate scheme when payoff functions (as functions of vectors of efforts) are kept as similar as possible across the two reward schemes. Eriksson et al. (2009b) experimentally examine an alternative explanation for the high variance in effort in simple rank-

[5] An important advantage of rank-order tournaments over alternative compensation schemes is that tournament incentives are not affected by common shocks (random noise that impacts all players equally), since common shocks do not change the relative ranking of players' efforts (Wu and Roe, 2005; Wu et al., 2006; Agranov and Tergiman, 2013). As a result of filtering common shocks, tournaments reduce agents' risk exposure, making them more attractive than other compensation schemes. Wu and Roe (2005) and Wu et al. (2006) show both theoretically and experimentally that in the presence of common shocks tournaments outperform fixed performance contracts and piece-rates by eliciting higher efforts.

order tournaments. They find that allowing subjects to choose their payment scheme between the tournament and the piece-rate scheme significantly reduces the variance of effort in rank-order tournaments. They also find that risk-averse subjects are less likely to participate in the tournament, which has an additional negative effect on the variance of effort.

In summary, there are four important lessons that we learn from experimental studies discussed in this section. First, most studies on lottery contests and all-pay auctions find significant overbidding relative to the Nash equilibrium prediction. Second, in contrast to lottery contests and all-pay auctions, there is very little overbidding in rank-order tournaments and aggregate effort usually conforms to the theoretical predictions. Third, in all three canonical contests there is significant heterogeneity in the behavior of individual subjects. Finally, in lottery contests and rank-order tournaments bids are usually distributed around the equilibrium, while in all-pay auctions the distribution of bids is bimodal, with some subjects submitting very low and others submitting very high bids.

3. Contest Structure

As discussed by Konrad (2009), even simple one-stage contests are often characterized by many parameters (i.e., number of players, heterogeneity of players and number of prizes) and they can have very different structures (i.e., incomplete information, risk aversion, spillovers and externalities). All of these factors play an important role in influencing the behavior of individual players. In this section we review the experimental literature investigating some of these factors.

3.1. Number of Players

Theoretically, it is not clear how the number of players impacts individual behavior in contests. For example, for the symmetric case it is generally true that when a contest is modeled as an all-pay auction or as a lottery contest, then the expected individual effort decreases with the number of players (Konrad, 2009). However, when the contest is modeled as a rank-order tournament, then, depending on the distribution of noise, the expected effort may decrease, increase, or remain unchanged when the number of players increases (Gerchak and He, 2003).

The experimental evidence on the effect of the number of players on individual behavior in contests is also somewhat mixed. Sheremeta (2011a), for example, finds that the average effort in a symmetric two-player lottery contest is 33% of the prize value, while in the corresponding four-player contest the average effort is 25% of the prize. Therefore, as predicted by the theory, the average individual effort decreases in the number of players. Morgan et al. (2012) also find support for this comparative static prediction with different group sizes. On the other hand, Lim et al. (2014) find that the average individual effort does not respond to the number of players. They attribute their findings to the fact that subjects make mistakes when choosing an effort level.

In all-pay auctions, Gneezy and Smorodinsky (2006) find that the average effort decreases in the number of players. On the other hand, Harbring and Irlenbusch (2003) document that the average effort weakly increases in the number of players. An explanation for these differences is that in Harbring and Irlenbusch (2003), subjects' efforts are restricted by a maximum effort cap set, while in Gneezy and Smorodinsky (2006), subjects can choose any effort (even higher than the prize value).

In rank-order tournaments, Orrison et al. (2004) find that the average effort does not change in the number of players when the noise component ε_i is uniformly distributed. List et al. (2014) investigate the effect of the number of players under different distributions of noise. They design three treatments in which, depending on the noise distribution, a risk-neutral contestant's effort should decrease, increase or remain the same. They find that, contrary to theoretical predictions, the average individual effort always decreases in the number of players.

To summarize, across the three canonical contests, the evidence seems to favor a negative relationship between group size and individual effort. However, such an interpretation should be taken with caution because the relationship between group size and individual effort depends both on the experimental design and the underlying theoretical structure.

3.2. Heterogeneous Players

The theoretical literature on contests has recognized that greater heterogeneity between players (appropriately normalized depending on the contest) leads to lower aggregate effort (Baye et al., 1993, 1996; Gradstein, 1995; Baik, 1994; Stein, 2002). The reason for this is the so called "discouragement effect." Although the technical details underlying the discouragement effect differ from model to model, they basically arise because a weaker player, either with higher unit costs of effort or a lower value of winning, finds it relatively unprofitable to try to beat the stronger player and, consequently, cuts back on his costly expenditure. This, in turn, may allow the stronger player to bid more passively as well when compared to a contest in which he faces a player of similar strength.

The impact of player heterogeneity on individual behavior has been thoroughly investigated in lottery contests. Davis and Reilly (1998), for example, compare a four-player symmetric lottery contest for a given prize with a five-player lottery contest in which the added player has a higher value of the prize. They find that adding the high-value bidder increases the total expenditure, which is consistent with the comparative static prediction. However, individual expenditures across the two contests for the four low-value players increase, which is not consistent with the comparative static prediction. Anderson and Stafford (2003) use a more complex design with a variable number of players, cost heterogeneity and an entry fee to study the theoretical predictions of Gradstein (1995). They find that, consistent with the theoretical predictions, cost heterogeneity reduces the aggregate number of players who enter. Moreover, for larger groups, higher heterogeneity decreases individual and aggregate efforts. Fonseca (2009), Anderson and Freeborn (2010) and Kimbrough et al. (2014) experimentally study lottery contests with heterogeneous players, where heterogeneity arises from the contestants' differing impacts on the CSF. All three studies find that, as predicted by the theory, more heterogeneity between players leads to lower effort in lottery contests.

The first study investigating a complete information all-pay auction with asymmetric players is Davis and Reilly (1998). Consistent with theoretical predictions, Davis and Reilly find that, introducing a higher valuation player into a model in which players have a given common value reduces the individual efforts of the original symmetric players relative to their efforts in the symmetric game. However, as before, there is significant overbidding, both in the benchmark symmetric game and the asymmetric game, with a substantial portion of the overbidding in the latter game being driven by the behavior of the stronger players. Fehr and Schmidt (2011) replicate these findings in an experiment designed to investigate the "exclusion principle" of Baye et al. (1993). Finally, Deck and Sheremeta (2012) find support for a discouragement effect in dynamic all-pay auctions with asymmetric players, where theoretical benchmarks (Konrad and Kovenock, 2009) suggest that the discouragement effect might be even stronger than in simultaneous move games.

Asymmetries have also been investigated in rank-order tournaments (Weigelt et al., 1989; Schotter and Weigelt, 1992). Weigelt et al. (1989), for example, study biased rank-order tournaments, and find that when one player has an unfair head-start over another, both players exert lower effort than symmetric players. Schotter and Weigelt (1992) extend this analysis to the case of both "unfair" (where the rules favor one identical player over another) and "uneven" (where players have different costs of effort) tournaments. As before, they find that either asymmetry between players reduces individual efforts.

3.3. Multiple Prizes

Theoretical research has shown that the optimal prize structure in contests depends on many factors (for a review see Sisak, 2009). Clark and Riis (1998) and Fu and Lu (2009), for example, show that in a symmetric lottery contest modified to allow multiple prizes the highest aggregate effort is obtained by offering one grand prize. Barut and Kovenock (1998) show that in an n-player symmetric contest in which the m-th highest bidder receives the m-th largest prize, any distribution of a fixed purse across n (nonnegative) prizes yields the same expected total expenditure as long as the lowest value prize is zero. Moldovanu and Sela (2001) show that in the all-pay auction with incomplete information and private values of a multiplicative coefficient in the cost function (reflecting idiosyncratic ability) one grand prize elicits the highest effort from participants when the common component of the cost of effort function is either linear or concave. However, if the contestants have a convex common component of cost several prizes may be optimal. Moreover, across a wide range of specific contest models, multiple prizes may generate higher efforts when contestants are risk-averse (Krishna and Morgan, 1998; Kalra and Shi, 2001) or heterogeneous (Szymanski and Valletti, 2005; Moldovanu et al., 2007).

There is a growing number of experimental studies investigating the optimality of the prize structure in contests (Harbring and Irlenbusch, 2003; Orrison et al., 2004; Müller and Schotter, 2010; Chen et al., 2011; Sheremeta, 2011a; Shupp et al., 2013; Lim et al., 2014; Stracke et al., 2014). These studies are based on different theoretical models (i.e., lottery contests, all-pay auctions and rank-order tournaments), and thus they are not directly comparable. Nevertheless, one aspect common to all of these studies is the assumption that the contest designer allocates a fixed amount of money either to one grand prize or split between multiple prizes.

Sheremeta (2011a) compares the performance of single-prize and two-prize lottery contests with four symmetric players, where the total prize value is held constant across the treatments. Consistent with the theoretical predictions of Clark and Riis (1998), the single-prize contest generates higher effort than multiple-prize contests. Shupp et al. (2013) also find that the single-prize contest results in a higher aggregate effort than the multiple-prize contest, although their theoretical model predicts that under risk neutrality both contests are equivalent. Stracke et al. (2014) show that even in a multi-stage elimination lottery contest between symmetric players, a single-prize generates higher efforts than when multiple prizes are allocated at the end of the contest.

Müller and Schotter (2010) experimentally investigate the all-pay auction model of Moldovanu and Sela (2001) and find that, consistent with equilibrium, in the case of a linear common cost component a one-prize contest generates higher efforts than a two-prize contest, whereas in case of a quadratic common cost component a two-prize contest generates higher efforts than a one-prize contest.[6] They also find that, although theory predicts effort levels that are continuous and increasing in the coefficient representing ability, observed effort is bimodal. Low ability players drop out and exert little or no effort, while high ability players try too hard and overbid.

Orrison et al. (2004), were perhaps the first to experimentally investigate how prize structure impacts effort in rank-order tournaments. They found that total effort is lower in tournaments with many small prizes than with few large prizes. However, in theory, multiple-prize contests may generate higher efforts if, for example, contestants are heterogeneous (Szymanski and Valletti, 2005; Moldovanu et al., 2007). Intuitively, if there is one very strong player and only one prize, then the weaker players may be discouraged from exerting effort as per the "discouragement effect" introduced in Section 3.2. Chen et al. (2011) investigate the optimal number of winning prizes in rank-order tournaments with heterogeneous contestants, where strong players have an ex ante advantage in terms of their initial endowment over weak players. They find that strong players increase their effort when the number of prizes is raised from one to two.

Finally, Kalra and Shi (2001) show theoretically that a multiple-prize rank-order tournament may generate higher total expenditure than a single-prize tournament when contestants are risk-averse. To test these predictions, Lim et al. (2009) investigate the optimality of a multiple-prize tournament in the presence of symmetric risk-averse contestants. Based on the model by Kalra and Shi, Lim et al. predict that multiple positive prizes, in which each prize is of different value, should generate higher efforts than a single prize. Consistent with the theoretical predictions, their experimental results indicate that increasing the number of winners generates higher effort under risk aversion.

3.4. Endogenous Prizes, Spillovers and Externalities

In many contests, it is appropriate to consider endogenously determined prizes that are functions of the profile of efforts rather than the more common assumption of an exogenous prize value. The endogeneity may be imposed by a designer, or may be the result of effort spillovers or externalities that arise naturally in the contest environment. Contests with endogenous prizes are especially interesting because theoretically they can generate qualitatively different predictions than contests with exogenous prizes (Chung, 1996; Baye and Hoppe, 2003; Long and Vousden, 1987; Chowdhury and Sheremeta, 2011a, 2011b, 2014; Baye et al., 2012). For instance, Baye et al. (2012) show that in some cases, all-pay auctions with endogenous prizes will have pure strategy equilibria. Recall that by contrast, all-pay auctions of complete information with exogenous prizes only have mixed strategy equilibria. Sacco and Schmutzler (2008) study an all-pay auction where endogenous prizes depend positively on own effort and negatively on the competitors' effort. They find evidence that subjects often coordinate on asymmetric pure strategy equilibria, where one player exerts all the effort while others exert no effort at all.

Cason et al. (2010) suggest that to attract more entrants into a contest it may be beneficial for a contest designer to use a proportional-prize structure. In the proportional-prize contest, there are no winners or losers as described in the payoff function (3) and determined by the probability specified in (2). Instead, each player i wins with certainty a prize $v_i(e_i, e_{-i})$ that is

[6] Freeman and Gelber (2010) conduct an experimental test of Moldovanu and Sela (2001) based on a real-effort experiment. They find that subjects' performance is higher when multiple prizes are offered than when a single prize is offered.

endogenously determined by the vector of efforts of the contestants. This yields a payoff structure similar to (4), but where $v_i(e_i, e_{-i})$ replaces $p_i(e_i, e_{-i})v$. The simplest form of a proportional-prize contest is a share contest in which efforts determine the shares of a prize v (i.e., instead of probabilistically, the prize is assigned proportionally). Cason et al. (2013) compare the performance of a share contest to a single-prize contest.[7] They find that, consistent with theory, single-prize contests generate higher efforts than share contests, but at the same time, share contests generate higher and more equitable payoffs. This specific feature of proportional-prize contests can explain why proportional prizes elicit higher entry rates than lottery contests with a single prize (Cason et al., 2010).

Baye et al. (2005, 2012) and Chowdhury and Sheremeta (2011a, 2011b, 2014) examine contests in which winner and loser prizes may be asymmetrically influenced by rival effort. For example, in innovation contests one firm's R&D effort may provide information spillovers that benefit its rival, the value of which may depend on the identity of the winner. Alternatively, in such a race the expenditure of a rival might decrease the patent value for the winner by hastening further innovation, creating a negative spillover. Another example where spillovers and externalities are important is litigation. Depending on the litigation system, losers have to compensate winners for a portion of their legal expenditures or, under one prominent proposal, up to the amount actually spent by the loser.

Several experimental studies have examined contests with spillovers. For instance, Dechenaux and Mancini (2008) have examined a two-player contest with a generalized contest payoff function as in Baye et al. (2005). Specifically, instead of a payoff function (3), the payoff for player i is given by

$$\pi_i(e_i, e_j) = \begin{cases} v_i - \beta e_i - (1-\alpha)e_j & \text{if } i \text{ wins} \\ v_i/2 - e_i & \text{if } i \text{ ties} \\ -\alpha e_i - (1-\beta)e_j & \text{if } i \text{ loses} \end{cases}. \tag{5}$$

The CSF in Dechenaux and Mancini (2008) corresponds to an all-pay auction. By contrast, Coughlan and Plott (1997) employ a lottery CSF and a payoff function that differs slightly from that in equation (5). As in contests without spillovers, both studies find significant overbidding in comparison to the Nash benchmark.

Cohen and Shavit (2012) study a lottery contest version of the sad loser auction (see Riley and Samuelson, 1981; Baye et al., 2012). In such a contest, the designer reimburses the winner's cost of effort (bid), so the payoff for player i is given by

$$\pi_i(e_i, e_j) = \begin{cases} v_i & \text{if } i \text{ wins} \\ -e_i & \text{if } i \text{ loses} \end{cases}. \tag{6}$$

Theory predicts that lottery contests with refunds should generate higher average bids than all-pay lottery contests (Matros and Armanios, 2009). The results of the experiment provide support for this prediction. Theory also predicts that the revenue of a contest designer should be higher in the lottery contest with refunds (once the cost of the winner's effort is refunded). This prediction is not supported in the experiment, mainly because low valuation players bid too low in contests

[7] Shared contests have also been studied by Fallucchi et al. (2013), Shupp et al. (2013), Chowdhury et al. (2014), and Masiliunas et al. (2014).

with refunds. Overall, Cohen and Shavit (2012) find evidence that subjects' behavior is more consistent with a corner solution, in which low valuation players bid zero.

3.5. Risk and Loss Aversion

Most of the theoretical results in the contest literature are derived under the assumption of risk neutrality. However, it is well documented that the majority of individuals are risk-averse (Holt and Laury, 2002). Most theoretical models of contests incorporate risk aversion by assuming that the utility function is non-separable in the prize value v and cost of effort $c(e_i)$. In this case, instead of the expected payoff function (4), the following expected utility function applies:

$$E(\pi_i) = p_i(e_i, e_{-i})U\big(v - c(e_i)\big) + (1 - p_i(e_i, e_{-i}))U\big(-c(e_i)\big). \qquad (7)$$

When examining the expected utility function (7) it is not clear how preferences impact individual behavior in contests. Millner and Pratt (1991) focused on symmetric two player contests and showed that risk aversion may not reduce total effort. They noted that, theoretically, the direction of the effect of risk aversion on effort depended on the third derivative of utility. If this was positive (a condition that has become known as "prudence") risk aversion would reduce total effort. Otherwise, total effort would increase. This observation was later extended to symmetric n-player contests by Treich (2010) and to a class of asymmetric contests by Cornes and Hartley (2012).

Millner and Pratt (1991) also carried out an experiment to assess the effect of risk aversion on effort. They found that more risk-averse subjects choose lower efforts than less risk-averse subjects, but efforts are still higher than predicted. Following Millner and Pratt, many studies have replicated the finding that risk-averse subjects exert lower effort in lottery contests than risk-neutral or risk-seeking subjects (Anderson and Freeborn, 2010; Sheremeta and Zhang, 2010; Sheremeta, 2011a; Mago et al., 2013; Shupp et al., 2013). Therefore, it appears that although theoretical predictions regarding risk aversion are ambiguous, the findings from experimental studies suggest that more risk-aversion leads to lower effort in contests.

Related to risk-aversion, there are several experimental studies examining the impact of loss-aversion on individual behavior in contests. Shupp et al. (2013), for example, compare individuals' decisions across three resource allocation contests which are isomorphic under risk-neutrality. They also elicit preferences toward risk, ambiguity and losses, and find that loss aversion preferences are best at predicting individual behavior in contests, with more loss-averse subjects exerting lower efforts than less loss-averse subjects. Experimental investigations of loss-aversion in contests also include Müller and Schotter (2010), Ernst and Thöni (2013) and Klose and Sheremeta (2012) for all-pay auctions and Gill and Prowse (2012) and Eisenkopf and Teyssier (2013) for rank-order tournaments.

3.6. Incomplete Information

A number of experiments have examined lottery contests and all-pay auctions in a private values environment. There is incomplete information because each bidder only knows his own valuation of the prize (or, alternatively, the marginal cost of effort). In most experiments, valuations (or costs) are drawn independently from uniform distributions. A theoretical analysis of lottery contests with incomplete information in a symmetric environment can be found in

Ryvkin (2010) and Wasser (2013) and treatments of all-pay auctions can be found in Krishna and Morgan (1997) and Moldovanu and Sela (2001).

Brookins and Ryvkin (2014) compare lottery contests with complete and incomplete information regarding the marginal cost of effort. Each player's marginal cost of effort is an i.i.d. draw from a uniform distribution. They show that with two players, whether or not information is complete does not affect equilibrium effort expenditure significantly. However, with four players, players with a low marginal cost (high marginal cost) submit lower (higher) effort bids under complete information than under incomplete information. These equilibrium predictions are borne out by the data, but not surprisingly, the authors also observe substantial overbidding.

Barut et al. (2002) were the first to experimentally examine all-pay auctions in a symmetric private values environment, but the focus of their study was all-pay auctions with multiple units. They assumed uniformly distributed private values for a single unit. Relative to the symmetric Bayesian Nash equilibrium, underbidding at low valuations and overbidding at high valuations was observed, and the outcomes were not always efficient, in the sense that higher-valued players did not necessarily win the units. In the aggregate, there was overbidding so that average revenue is higher than predicted. The follow up study by Noussair and Silver (2006) used six-player single-prize all-pay auctions, again with uniformly distributed private values. They also found aggregate overbidding relative to the Bayesian Nash equilibrium, with average revenues far above the theoretically predicted expected revenue. As in Barut et al. auction outcomes were not always efficient. When considering subject level data, a prominent outcome in both Barut et al. and Noussair and Silver is the phenomenon Müller and Schotter (2010) refer to as *bifurcation*: low-valuation subjects underbid, while high-valuation subjects tend to overbid. For instance, Figure 6 is drawn from data obtained from Noussair and Silver (2006). The frequency of zero bids is much higher than predicted by equilibrium behavior. For example, in the Bayesian Nash equilibrium only subjects with a valuation of zero should bid zero, whereas in the experiment, the modal bid for subjects with valuations in the 25th percentile appears to be zero. It was also common for subjects with valuations in the 75th percentile to place bids near their valuation.[8] Müller and Schotter (2010) invoke loss aversion to explain bifurcation. By contrast, Minor (2012) uses the concept of "coarse thinking," a psychological phenomenon by which subjects collapse possible competitors into a single stereotype (i.e., strong and weak).

In the papers mentioned above players are ex-ante symmetric, i.e., their values (or costs) are independently drawn from the same distribution. Wärneryd (2003) analyzes a two player lottery contest in which one contestant is informed of the common value of the prize prior to bidding, while the other player knows only the continuous distribution from which this value is drawn. Grosskopf et al. (2010) experimentally study asymmetric information contests reminiscent of Wärneryd (2003), and find that, in general, informed bidders tend to bid more aggressively than uninformed bidders. Interestingly, the average sum of bids in asymmetric information lottery contests and all-pay auctions are not statistically different, while they differ under symmetric information. The empirical result for asymmetric information contests does not conform to the theoretical prediction, which is that expected revenue in the all-pay auction is greater than expected revenue in the lottery contest.

[8] In two-player all-pay auctions, Dechenaux and Mancini (2008) find that low-valuation players behave more aggressively than in Noussair and Silver's (2006) six-player auctions, suggesting that this finding does not prevail in smaller auctions.

In summary, the main lesson that we learn from experimental studies discussed in this section is that most studies find support for the comparative statics predictions of contest theory. Some commonly supported comparative statics results are the impact of incomplete information on individual behavior, the "discouragement effect", and the impact of contest parameters (e.g., the number of players and the number of prizes) on effort.

4. Dynamic Contests

In this section we discuss contests with a dynamic structure. That is, contests in which some players can make decisions based on the actions of others. First, we discuss contests in which players move sequentially. Second, we discuss wars of attrition, which are multi-period contests of exit, which in some contexts can be interpreted as simultaneous move contests. Third, we examine a class of multi-stage contests with a finite horizon in which the set of players remains fixed. These include patent races and best-of-*n* contests. Fourth, we discuss multi-stage elimination contests, in which a certain number of players are eliminated at each stage of the competition. Finally, we conclude with a discussion of endogenous entry into contests.

4.1. Sequential Contests

In a sequential contest, the players choose effort sequentially, with players moving later in the game observing the previous players' choices. Dixit (1987) derives theoretical predictions for two-player sequential contests under standard assumptions on the CSF which include the lottery CSF as a special case. If players are symmetric, then the simultaneous move Nash equilibrium effort levels constitute a subgame perfect Nash equilibrium (SPNE) outcome. By contrast, if the leader is a favorite, in the sense that his probability of winning the contest in the simultaneous move Nash equilibrium is greater than one half, then the leader's SPNE effort level in the sequential contest is higher than under simultaneous moves. Leininger and Yang (1994) show that with the Tullock CSF with $r > 2$ and symmetric players, in the unique SPNE, the first-mover preempts the second-mover by expending an effort level that forces the second-mover to expend zero. In a game such as Dixit's (1987) in which the choice of timing is endogenized, Baik and Shogren (1992) show that in a SPNE, the favorite chooses to follow whereas the underdog chooses to lead. They use this result to argue that the favorite would not lead aggressively and, in fact, endogenous leadership by the underdog causes both players to expend less effort than under simultaneous moves. This theoretical prediction forms the basis for a number of related experiments.

First, Shogren and Baik (1992) investigate the form of exogenous leadership that does not arise in their game of timing, the case of the "favorite leader" – "underdog follower" sequential contest. Assuming a lottery CSF, they compare behavior in this dynamic game to behavior in the simultaneous move contest. Their experiments identify several key behavioral departures from Dixit's prediction. In the sequential contest, favorite first-movers submit effort levels that are no different from the favorites' expenditures in the simultaneous move game. Overall, second-movers best respond to the first-movers' choices. Finally, the authors note that in their role as followers, underdogs sometimes seek to equalize the probability of winning across players rather than maximize their expected payoff.[9]

[9] Using a real-effort experiment, Gill and Prowse (2012) study a sequential-move tournament in which the second mover observes the first mover's performance before choosing how much effort to expend. The results of the experiment provide evidence of a discouragement effect: second movers decrease their effort after observing a high effort by the first movers.

Weimann et al. (2000) also examine a sequential two-player contest, but employ a design with symmetric players and the Tullock CSF with $r = 8$. In equilibrium, the first-mover preempts the second-mover by submitting the lowest effort level for which the second-mover's best response is to play zero. A striking finding is the lack of evidence for a first-mover advantage in the data. In many instances, second movers earn average payoffs above those earned by first-movers. As Vogt et al. (2002) state when referring to Weimann et al.'s results, it appears as though second-movers "punished preemptive attempts and exploited cooperative attempts" (pg. 74).

Fonseca (2009) reconsiders experimental sequential contests under both symmetric and asymmetric conditions. More specifically, his experiment allows for a two-by-two comparison of contests by varying both the degree of symmetry between players (symmetric versus asymmetric) and the timing (simultaneous versus sequential). In the contest with symmetric players but asymmetric timing, first-movers submit effort levels in excess of the prediction. In contests with asymmetric players and timing, Fonseca's findings replicate Shogren and Baik's (1992) results to some extent. Favorite first-movers often fail to exploit their theoretically predicted first-mover advantage. Although a large proportion of preemptive attempts succeed, such aggressive (equilibrium) behavior by first-movers sometimes engenders retaliation by the second-mover. Indeed underdog second-movers often submit rather large effort levels, a behavior that can be rationalized by inequality aversion.

Vogt et al. (2002) study contests in which players alternate in submitting bids and each player's bids are summed across the duration of the contest to determine a player's overall or total bid. At each point in time, previously submitted bids are public information and the window of opportunity during which contestants may submit bids closes after a randomly determined number of rounds. This design is broadly similar to that in Weimann et al. (2000) and is meant to experimentally implement Leininger and Yang's (1994) infinite horizon alternating move model. In that model there exists a Markov perfect equilibrium in which tit-for-tat strategies are employed, generating a path of play on which bidding ends with the second mover (who bids zero). The experimental data exhibit patterns reminiscent of this equilibrium. Contestants stop accumulating effort relatively quickly (after 6 to 10 periods) so that bidding never escalates. As a result, average earnings are higher than in Weimann et al.'s simple leader-follower games. These findings suggest that alternating-move contests with an uncertain final period yield more efficient outcomes than one-shot leader-follower contests.

The experiments discussed above involved either exogenously specified leader-follower roles or alternating moves. Baik et al. (1999) examine the natural extension of the leader-follower setting to a game where the choice of timing is endogenous. In the first stage of the game, the players simultaneously choose either to commit to an effort level or to wait. If one player, the endogenous leader, immediately commits to an effort level and the other player, the endogenous follower, waits, then the follower learns the leader's effort level and must choose his own effort level. If both players choose to wait, then they play a simultaneous contest. The results of the experiments indicate that subgame perfection predicts actual timing choices rather well. In particular, when subjects are given up to two days to think about their strategy, in a majority of cases, favorites endogenously choose to follow and underdogs choose to lead.

4.2. Wars of Attrition

Since the introduction of the "war of attrition" by Maynard Smith (1974), the model has been applied extensively in the field of biology. In the economics literature, the first experimental study of the war of attrition is Bilodeau et al. (2004).[10] They test a dynamic model of the *volunteer's dilemma* in which the clock stops as soon as one participant volunteers.[11] This model is similar to a discrete time war of attrition with complete information and a finite horizon. In five different treatments, the authors consider various parameters that influence the players' benefit and cost of public good provision. Subgame perfection accurately predicts the identity of the volunteer only 41% of the time. One of the key departures from subgame perfection is that subjects rarely volunteer immediately. However, behavior responds to incentives in a sensible manner. For instance, other things equal, players with a greater benefit from volunteering do volunteer more often than other players. Similarly, other things equal, players with a lower cost of volunteering are more likely to stop the clock first. These qualitative predictions are consistent with a descriptive model in which contestants have "first-order beliefs" (see for instance, Nagel 1995). In this model, the contestants believe their opponents' volunteering times are random draws from an identical distribution and they choose their volunteering time to maximize their expected payoff.[12]

Hörisch and Kirchkamp's (2010) experiment offers a direct comparison of the all-pay auction, the static representation of the war of attrition (i.e., the second-price all-pay auction) and the dynamic war of attrition (where an actual clock runs and the loser is the first player to stop it). In contrast to Bilodeau et al. (2004), Hörisch and Kirchkamp set up an environment with private costs drawn independently from an identical distribution. One of the main qualitative implications is that in the symmetric equilibrium of the war of attrition, almost all player types do not stop immediately. Moreover, the static and dynamic wars of attrition have the same symmetric equilibrium. In the laboratory, the authors find that overbidding prevails in the all-pay auction and the static war of attrition. However, subjects tend to undersupply effort in the dynamic war of attrition by stopping the clock earlier than predicted. For all treatments, the authors test for evidence of bifurcation in empirically estimated bidding functions, but even in the all-pay auction, they find no significant evidence of the commonly-observed behavioral pattern.

Oprea et al. (2013) design an experiment based on the duopoly model of Fudenberg and Tirole (1986). In this model, two firms must decide whether or not to remain in a market or to exit. A player's cost per unit of time of remaining in the market is private information and for a large range of these unit costs, duopoly profit is negative and monopoly profit is positive. For such values of unit costs, remaining in a duopoly market has an instantaneous cost equal to duopoly profit and a future benefit to a surviving firm equal to the monopoly profit. Oprea et al.'s design varies the dispersion in the distribution of costs to induce more or less uncertainty

[10] The first experimental study of a competitive environment resembling a war of attrition is Phillips and Mason (1997). However, in the dynamic Cournot game they analyze, players do not choose the time at which they wish to exit. Rather, a player remains in the game until he is forced to exit when his cumulative profit falls to zero.

[11] The static *volunteer's dilemma* is a simultaneous move game in which each of n players has two actions, "volunteer" and "not volunteer". Any player who volunteers incurs a cost, c. If at least one player volunteers then all players receive an identical prize, v. If none of the players volunteer, then all players earn a payoff of zero. If $v - c > 0$, the game has multiple Nash equilibria, including pure strategy equilibria in which one player volunteers and $n - 1$ players do not volunteer, as well as a symmetric equilibrium in non-degenerate mixed strategies. Diekmann (1985, 1986) experimentally studies symmetric games and the effect of the number of players on the probability of volunteering, and finds that a player's likelihood of volunteering is decreasing in the number of players. Diekmann (1993) experimentally studies an asymmetric version of the game where players differ in their cost of volunteering, and finds that the players with the lowest cost of volunteering are more likely to volunteer.

[12] The experiment by Otsubo and Rapoport (2008) also implements a finite horizon, complete information war of attrition (framed as a dynamic *volunteer's dilemma*), but focuses on symmetric players.

regarding the rival's cost. Observed behavior conforms rather well to the point prediction for exit times. As expected, there is a negative relationship between cost and exit time overall. Furthermore, when the degree of cost asymmetry between firms is high, high-cost firms tend to exit earlier than low-cost firms.

DeScioli and Wilson (2011) observe behavior in an experiment that requires self-selection into an asymmetric war of attrition. Unlike previous economic experiments, their experimental procedures are contextualized and meant to replicate the environment found in typical animal behavior experiments. Each subject controls an "avatar," a virtual character that competes with other avatars over scarce resources located at various points of a virtual field. In one of the treatments, the resources are uniformly distributed across the field and in another treatment, they are clustered in patches. When encountering a rival avatar, a subject may "fight" (equivalent to a constant positive bid), "smile" (equivalent to a zero bid) or "travel" to another location. There are two types of players, large and small, and fights may arise between participants of equal size or between asymmetric participants. In the experiment the authors find that fights are much more frequent in the patchy than in the uniform treatment. Moreover, their experimental results indicate that an ownership convention develops in the patchy treatment because, in the resulting wars of attrition, residents are more likely to win than intruders, even after controlling for size.[13]

4.3. Races

The seminal work by Harris and Vickers (1985, 1987) on races provides a rich set of predictions in the theory of dynamic contests. In their models, two players each start at a finite distance from the finish line. In Harris and Vickers (1985), the two players take turns advancing a continuous distance, with a convex per unit cost of advancing within each period and progress that is deterministic. By contrast, in Harris and Vickers (1987), players engage in a sequence of component contests and each firm must win a certain (potentially different) number of contests in order to win the race. At the end of each component contest the contestants receive full feedback regarding the outcome of the stage game and their position in the race. Progress is stochastic, with the outcome of each contest determined by a type of modified Tullock lottery contest in which the cost of bidding is not only a function of the player's own effort, but is decreasing in the other player's effort.

Zizzo's (2002) experiment seeks to implement Harris and Vickers's (1987) multi-stage race in the laboratory. Harris and Vickers provide a limited set of analytical results which can be used as point predictions, but provide several qualitative results. Zizzo (2002) derives several hypotheses based on their analysis. First, one implication of the Harris and Vickers analysis is that the leader (the player requiring the smaller number of consecutive component contest wins to win the contest) expends more than the follower in a given component contest. Second, the correlation between the gap (the difference between the number of consecutive wins needed to win the contest by the leader and by the follower) and component contest expenditure is more negative for the follower than for the leader. Third, as the gap increases, a threshold is reached beyond which the leader incurs almost all of the component contest expenditure. To test these hypotheses, Zizzo implements races with two subjects and a Tullock lottery CSF in each component contest. One of the key findings is that leaders do not invest significantly more than followers, unless the gap is extremely wide (that is, followers are five or more steps behind).

[13] In a recent paper, Caldara (2012) examines complete information common value pay-to-bid auctions, which resemble wars of attrition.

Therefore, the first hypothesis is rejected, while the data exhibit mitigated support for the third hypothesis. The data provide better support for the second hypothesis, suggesting that as the gap increases, discouragement affects the laggard's behavior.

The best-of-three contest examined by Mago et al. (2013) is similar to a race. Two players compete in a contest lasting at most three stages. The first player to win two stages obtains the final prize.[14] As in Zizzo (2002), in Mago et al. (2013), two players engage in a simultaneous move Tullock component contest in each stage. There is perfect observability between stages. In Zizzo's set-up, the winner is the first player to achieve ten successes, while in Mago et al., the winner is the first player to achieve two successes. Another key difference is that in Mago et al., a player obtains an intermediate prize for winning a stage, while there is no such prize in Zizzo. Moreover, Mago et al. vary r in the CSF in two separate treatments, $r = 1$ and $r = 0.4$. Finally, Mago et al. consider a linear cost of effort, whereas in Zizzo the cost function is quadratic. In contrast to Zizzo, Mago et al. (2013) find that leaders expend more effort than followers. That is, stage 1 winners invest more than stage 1 losers, an effect they refer to as *strategic momentum*. They also find that including intermediate prizes increases both overall effort and the length of the race, results which both conform with the relevant theory. Finally, increasing the role of chance by lowering r decreases the likelihood of the race ending in two rounds.[15]

Finally, Deck and Sheremeta (2012) employ a special case of a model of a race due to Konrad and Kovenock (2009) in which each component contest is an all-pay auction. Deck and Sheremeta interpret the model as a game in which an attacker of a resource and the resource's owner engage in what is potentially a sequence of $n > 1$ component contests over the resource. The defender must win each of the contests to secure the resource and the attacker need only win one contest to capture the resource. For the pair of defender prize values chosen in their experiment, the defender's optimal strategy is either to fight all battles by employing the same mixed strategy in every component contest or to give up and expend no effort. In the former case, the attacker responds by lowering his expected effort expenditure with each new battle. The qualitative findings of the experiment correspond to the theoretical predictions except for one key pattern. When fighting, rather than expending the same (respectively, lowering) expected effort in each new component contest, the defender (respectively, attacker) increases effort.

4.4. Multi-Stage Contests with Carryover

An important aspect of multi-stage contests is that effort may carry over from one stage to the next. In the models of races in Section 4.3, the effort expended in a given stage could not be used in subsequent stages.

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[14] Irfanoglu et al. (2014) also investigate a best-of-three contest and compare its performance with a static contest. Mago and Sheremeta (2014) examine the best-of-three contest modeled as an all-pay auction. Their results are qualitatively similar to the findings of Mago et al. (2013).

[15] The above studies provide evidence on behavior in races where opportunities for cooperation are nonexistent. Silipo (2005) sets up an experiment to examine the incentives for cooperation that may arise before the start of a patent race or emerge during its course. His model is based on Fudenberg et al. (1983) but allows for collusion. Silipo employs a three-by-two design that varies the degree of asymmetry in starting positions and the value of the prize. He observes rather high rates of cooperation, but mostly when the players are symmetric. With asymmetries, in the sense that one of the subjects has a head start in the race, cooperation does not emerge as often. Furthermore, when the prize value is low, any cooperation typically breaks down as contestants approach the finish line. Like the Harris and Vickers models, Fudenberg et al.'s (1983) model exhibits the property that once a player has established a sufficient lead, this player makes all the investment while the laggard gives up. For duopolies that do not cooperate, Silipo does find evidence that points to such a discouragement effect.

A number of recent studies have used the Tullock CSF to examine contests with carryover.[16] In Schmitt et al. (2004) the same bidders interact in a sequence of contests. A participant's bids accumulate over time but they depreciate at a constant, non-negative depreciation rate. Schmitt et al. (2004) consider three values for the carryover rate and they also vary feedback conditions. The main finding is that, contrary to equilibrium, carryover reduces overall expenditure. Furthermore, carryover induces contestants to expend more effort in the first than in the second stage. Interestingly, in a two-stage elimination contest and a related design, Sheremeta (2010a) also finds that the effect of carryover is to increase first-stage effort levels and decrease second-stage effort. However, contrary to Schmitt et al. (2004), the total effort increases in the carryover rate. Hence, the efficiency effect of allowing effort carryover can be either positive or negative depending on whether the multi-stage contest has an elimination structure.[17]

Ryvkin (2011) investigates another aspect of effort carryover, namely fatigue. Players engage in a best-of-*n* overall contest and may choose one of two effort levels in each contest, high and low. Players who choose the high effort in a component contest decrease their probability of winning in later component contests. The model is constructed so that in the absence of fatigue choosing high effort in all stages is a dominant strategy. When fatigue is possible, high effort in all stages of the contest is no longer an equilibrium. In the experiment, Ryvkin tests the major predictions of the model and finds that subjects strategically respond to changes in the parameters of the contest in a manner predicted by equilibrium behavior.

4.5. Multi-Stage Elimination Contests

Many contests in practice consist of multiple players and multiple stages. In each stage contestants exert efforts in order to advance to the final stage and win a prize. At the end of each stage, a specific number of contestants are eliminated from participation. Such contests are prevalent in real life; however, empirical studies of multi-stage elimination contests are hard to conduct due to endogeneity and selection problems (Szymanski, 2003). For this reason, many multi-stage elimination contests have been studied in a laboratory setting.

Parco et al. (2005) and Amaldoss and Rapoport (2009) investigate a symmetric two-stage elimination lottery contest, where each player has a budget constraint that constrains his total expenditure of effort across the two stages. In the first stage, players compete by expending effort within their own groups, and the winner of each group proceeds to the second stage. In the second stage, players compete with one another to win a prize by expending additional effort subject to their overall budget constraint. Parco et al. (2005) study this model with a two-group two-player experimental design, and find significantly higher effort than predicted in the first stage and, as a consequence, significantly lower effort in the second stage. They conjecture that a non-monetary value of winning and misperception of the probabilities of winning play a crucial role in explaining these findings. Amaldoss and Rapoport (2009) further test this conjecture in a similar symmetric two-stage elimination contest with larger group sizes: a three-group eight-player and an eight-group three-player contest. As before, they find first-stage effort levels that

[16] An early study of a contest in which effort from previous stages is carried over to later periods is Sbriglia and Hey's (1994) real-task experiment.

[17] In multi-stage contests, with or without carryover, the discount rate that players apply to future payoffs affects the intertemporal allocation of effort. Deck and Jahedi's (2014) experiment seeks to test whether individual contestants discount future gains and whether they strategically anticipate that others also discount future payoffs.

are significantly higher than predicted. The results also suggest that the utility of winning, rather than misperception of the probabilities of winning, plays a crucial role in explaining the data.[18]

Sheremeta (2010a, 2010b) investigates two-stage elimination contests with a lottery CSF and constant unit cost of effort (without budget constraints). Sheremeta (2010b) also compares the performance of a two-stage contest to a revenue equivalent one-stage contest. Contrary to the theoretical predictions of Gradstein and Konrad (1999), the two-stage contest generates higher aggregate effort than the corresponding one-stage contest, and efforts are higher than predicted by the SPNE in both stages of the two-stage contest. Additionally, Sheremeta shows that a simple behavioral model featuring a non-monetary utility of winning explains both efforts higher than the theoretical benchmark and the difference between the efforts expended in the one-stage and two-stage contests.

Höchtl et al. (2014) study a two-stage lottery contest similar to Sheremeta (2010a, 2010b). The main difference, however, is that instead of being homogeneous, players are one of two types: strong or weak (low or high marginal cost). Höchtl et al. show both theoretically and experimentally that total effort is maximized if strong players compete against each other in the first stage of the contest. On the other hand, a strong player is more likely to win the elimination contest if strong players compete against weak players in the first stage of the contest.

Amegashie et al. (2007) study a two-stage elimination all-pay auction with heterogeneous players and budget constraints. In the experiment there are four players, each with a different valuation for the prize. In the first stage, all players place their bids and the two highest bids proceed to the second stage. The two winners of the first stage place their bids in the second stage, subject to the remaining budget constraint. Amegashie et al. find that subjects behave according to the SPNE, which involves "burning out" by using all of the available budget in the first stage. They also find that subjects exert significantly higher bids when groups are larger, thus concluding that more competition leads to higher bids, and that burning out is a competitive phenomenon.

Finally, Altmann et al. (2012) conduct an experimental investigation of a two-stage elimination rank-order tournament and compare its performance to a revenue equivalent one-stage tournament. Consistent with previous findings on rank-order tournaments (Bull et al., 1987), average effort in a one-stage tournament is close to the Nash equilibrium. In contrast, subjects in the two-stage tournament exert a higher effort in the first stage than in both the SPNE benchmark and the equivalent one-stage tournament. This finding is robust to a pointwise increase in the marginal cost of effort obtained by making the cost function more convex. Combined with the findings of Sheremeta (2010b), the fact that the over-expenditure of effort is significantly higher in the two-stage contest than in the one-stage contest suggests that there is a fundamental difference between subjects' behavior in two-stage and one-stage elimination contests. Whether this pattern is due to a non-monetary utility of winning, sunk cost fallacy, misperception of the probabilities, or yet another behavioral anomaly remains an open question.

4.6. Endogenous Entry

There is a growing interest in endogenous participation in contests. One of the first experimental studies to address this issue is Fullerton et al. (1999), who base their experimental

[18] Chark et al. (2011) study two-stage elimination lottery contests with large group sizes, no binding constraints, and groups that are of unequal sizes. Qualitatively, their results are similar to Parco et al. (2005) and Amaldoss and Rapoport (2009), although Chark et al. find little evidence for over-expenditure in the first stage.

design on Taylor's (1995) innovation tournament model.[19] Fullerton et al. (1999) find substantial support for the model's comparative statics predictions, indicating that subjects optimally choose to participate in research contests by employing effort expenditures that are influenced by the number of contestants, the value of the prize and the cost of effort.

Anderson and Stafford (2003) build their experimental design on the theoretical model of Gradstein (1995), which extends Tullock's (1980) model by introducing an entrance fee and asymmetric cost structure. They find that, consistent with theoretical predictions, low ability (high cost) contestants frequently choose not to participate in the lottery contest and instead opt out for a fixed payment. In a related study, Morgan et al. (2012) design an experiment using the Tullock lottery contest where subjects may choose whether to participate in a contest or obtain a fixed payment as an outside option. Morgan et al. examine cases with both relatively large and small contest prizes. They find that, consistent with theory, contest entry and effort expenditures increase with the size of the prize. However, they also find that when the prize is small, there is more participation than predicted (over-entry) and contest participants earn less than the outside option. On the other hand, when the prize is large, there is under-entry and contest participants earn more than predicted.

Eriksson et al. (2009b) conduct an experiment where subjects can choose to enter the Lazear-Rosen rank-order tournament or be paid according to a payoff equivalent piece-rate incentive scheme. They find that subjects choose tournaments about 50% of the time. Using Holt and Laury's (2002) elicitation procedure for risk preferences, Eriksson et al. show that the more risk-averse subjects are, the less likely they are to enter tournaments. Dohmen and Falk (2011) use a similar approach by letting subjects self-select into one of the four payment schemes, including a fixed payment, piece-rate, tournament and a revenue-sharing scheme. The results of the experiment demonstrate that subjects systematically sort into different payment schemes. When the choice is between a fixed payment and a tournament, subjects are more likely to enter the tournament if they are less risk-averse, more productive and more optimistic.

Bartling et al. (2009) use a real-effort experiment to study how subjects' distributional preferences influence their decisions to enter a tournament or a piece-rate incentive scheme. They find that inequality-averse subjects are less likely to enter the tournament. Similarly, Balafoutas et al. (2012) document that, controlling for beliefs, inequality-averse and spiteful subjects are less likely to enter tournaments. Finally, Niederle and Vesterlund (2007) document that men enter tournaments significantly more often than women. In summary, all of these findings highlight the importance of endogenous sorting when players are allowed to choose other opportunities and the tendency for rank-order tournaments to systematically attract people with specific individual characteristics, including people that are less risk or inequality averse.

Several studies examine entry decisions into alternative contest structures. Vandegrift et al. (2007), for example, report a real-effort experiment in which subjects choose between a piece-rate, a single-prize and multiple-prize lottery contests. They find that, holding total payments constant across contests, effort is higher in the single-prize contest than in a multi-prize contest. However, entry rates into the single-prize contest are lower than into the multi-prize contest. Consequently, Vandegrift et al. conclude that the single-prize contest is more efficient in generating higher effort but less efficient in inducing entry and identifying the most capable players from the given pool of participants.

[19] Baye and Hoppe (2003) show that the innovation tournament is strategically equivalent to a Tullock contest with an endogenous prize.

Another experimental study that compares entry into alternative contest structures is Cason et al. (2010). Cason et al. employ a real-effort experiment in which subjects can choose between a piece-rate, a single-prize and proportional-prize contest, each with the same total prize value. They find that a proportional-prize contest attracts more entrants and generates more aggregate effort than a single-prize contest. The proportional-prize contest performs better by encouraging entry and a performance of low ability players, without discouraging entry or the performance of high ability players.

5. Static Multi-Battle Contests

In a wide range of disciplines, including computer science, political science, economics, management science, and the military sciences, there are environments that may be characterized as games of multiple contests with linkages (Kovenock and Roberson, 2012). These games have long attracted the attention of theorists and, more recently, have been the subject of experimental investigation.

5.1. Constant-Sum Colonel Blotto Games

The Colonel Blotto game has its roots in a paper by Borel (1921) in which two players must simultaneously select an ordered triple of three nonnegative numbers which sum to a common constant and the winning player is the player who chooses the higher number in two of the three components of the triple. According to McDonald and Tukey (1949), Colonel Blotto games were examined in the process of solving practical military problems by Charles P. Winsor and Tukey at Princeton during World War II. Since then, substantial theoretical work on these games was undertaken in the context of military operations research, computer science, political science, management science, and economics (for a review see Kovenock and Roberson, 2012). These theoretical contributions have spurred a host of experimental tests of Colonel Blotto models.[20]

Avrahami and Kareev (2009) study a discrete constant-sum Colonel Blotto game as in Hart (2008) in which players maximize the expected number of battlefields won subject to a budget constraint. They look at both symmetric and asymmetric budgets. The results of the experiment support the qualitative predictions of the theory. Specifically, as predicted, the weaker players (with lower budgets) allocate zero resources to a subset of battlefields. The number of battlefields to which the weaker players allocate zero resources increases in the relative strength of their opponents.

Chowdhury et al. (2013a) provide an experimental test of the theoretical predictions of the Colonel Blotto game with a continuous strategy space in which players maximize the expected number of battlefields won subject to asymmetric budgets. The experiment has separate treatments with an auction CSF and a lottery CSF based on the theoretical treatments of Roberson (2006) and Friedman (1958), respectively. Due to the constant-sum nature of the game, the experiment also compares a fixed matching protocol (where subjects are paired for all 15 rounds) and a random matching protocol (where subjects are randomly re-matched after each round). The results of the experiment provide support for the main qualitative predictions of the theory. In the auction treatments, the weaker players often use a "guerilla warfare" strategy which stochastically allocates zero resources to a subset of battlefields. The stronger players often employ a "stochastic complete coverage" strategy, allocating random, but positive,

[20] Recently, the Colonel Blotto game became available on Facebook, known as Project Waterloo (Kohli et al., 2012).

resource levels to each battlefield. However, subjects also exhibit significant serial correlation across periods in allocations to a given battlefield, which is not predicted by the theory. This correlation is reduced under the fixed matching protocol, but it is not entirely eliminated. Under the lottery treatments there is support for the equilibrium prediction of a constant allocation across all battlefields for both players.

Cinar and Goksel (2012) compare Colonel Blotto games with symmetric resources and asymmetric resources. They also vary the number of battlefields. An interesting feature of their design is that in each treatment, subjects play for 12 periods against a computer which is programmed to play an optimal strategy derived from the theory. The results of the experiment indicate that in all treatments the aggregate behavior of all subjects is well predicted by the theory. As in Chowdhury et al. (2013a), subjects' payoffs are relatively close to the theoretical benchmarks. Nevertheless, in the asymmetric case, computer generated strategies outperform strategies chosen by subjects and thus, in this case, subjects usually receive lower payoffs than predicted by the theory.

Finally, Arad (2012) examines a Colonel Blotto game between symmetric players, in which resources cannot be allocated continuously, but instead, are clustered into several partitions, which represent different levels of force. The player who allocates a greater level of force to a battlefield wins that battle. Arad motivates this game as a "tennis coach problem," where a coach has to allocate four tennis players of different skills (resources of different values) among four positions (battlefields). The objective is to win a majority of the battlefields. The results of the experiment show that most subjects use only a small number of strategies, disregarding a large set of potential strategies. The behavior of some subjects can be explained by an adapted level-*k* model of iterating reasoning (Stahl and Wilson, 1994).

5.2. Non-Constant-Sum Blotto-like Games

The classical formulation of the Colonel Blotto game is as a constant-sum game. Players are budget constrained and resources allocated have zero opportunity cost; that is, resources are "use it or lose it." However, there are a number of related formulations in which the game is non-constant-sum. One example is the case in which unused resources have positive value (Szentes and Rosenthal, 2003; Klumpp and Polborn, 2006; Kvasov, 2007, Roberson and Kvasov, 2012).

Mago and Sheremeta (2014) investigate the non-constant-sum multi-battle contest that is the all-pay auction special case of the chopstick-auction examined by Szentes and Rosenthal (2003). In their contest two players simultaneously expend effort in three battles. The player expending the highest effort in a battle wins that battle with certainty (i.e., the auction CSF) and the player who wins the majority of the battles (two or more) wins the contest. Players pay an identical constant unit cost of effort in each battle. Consistent with other experimental findings on single-battle contests, Mago and Sheremeta (2014) find significant over-expenditure of resources relative to the Nash equilibrium benchmark. Consistent with the theory, subjects make positive but random allocations in each battle and allocations fall within the theoretically predicted univariate supports. Contrary to the theory, subjects often make positive allocations in only two out of three battles (instead of all three) and they significantly overuse moderately high allocations.

Irfanoglu et al. (2014) also investigate a three-battle contest similar to Mago and Sheremeta (2014). However, the main difference is that the probability of winning the battle is determined by the lottery CSF. Nash equilibrium requires that subjects allocate an equal expenditure across the three battles (Klumpp and Polborn, 2006). However, contrary to this prediction, none of the subjects employ a uniform expenditure strategy. Most subjects vary their expenditure between battles in a given period and within battles over time, although such dispersion of expenditure decreases as the game is repeated (with random matching).

Arad and Rubinstein (2012) examine a version of the Colonel Blotto game between symmetric players using a combination of a large scale web-based experiment and classroom experiments. In their experiment, players are symmetric. Players choose their strategies once and these strategies are played in a tournament against the strategies of all other players in the session, and the player with the most battlefields won wins the overall game. Within each battlefield an auction CSF is used, but in the case of a tie neither of the players is awarded the battlefield. Thus, the standard constant-sum Colonel Blotto game is transformed into a non-constant-sum game due purely to possible ties. Arad and Rubinstein provide a theoretical prediction for subjects' behavior based on multi-dimensional iterative reasoning, and discuss in details the type of strategies that are most successful in achieving the highest payoff in the Colonel Blotto game. These strategies generally involve the almost complete neglect of two battlefields, often the endpoint (first and last) battlefields, with moderately high allocations to four battlefields.

5.3. Asymmetric Objectives

Often players may have asymmetric objectives when participating in multi-battle contests. For example, in patent races firms often must obtain a cluster of patents in order to produce a commercially viable product. In military battles, the attacker's objective is often to successfully attack only one target, or a subset of targets, and the defender's objective is to successfully defend all targets.

Kovenock et al. (2010) experimentally investigate a two-player multi-battle contest in which players have asymmetric objectives. In this game a risk-neutral attacker and defender simultaneously allocate a scarce resource obtained at constant unit cost across the set of battlefields. The battlefields form a weakest-link network for the defender. The attacker receives a prize if he wins at least one battle. The defender receives a prize if he wins all battles. For each player, the probability of winning any given battle is determined either by the auction CSF (Kovenock and Roberson, 2010) or the lottery CSF (Clark and Konrad, 2007). For both CSF's, the Nash equilibrium depends on the ratio of the defender's valuation of the prize to the attacker's valuation. There is a key distinction between equilibria under the auction CSF and the lottery CSF. With the auction CSF, the attacker employs a "guerilla warfare" strategy by exerting effort in attacking at most one randomly chosen target. On the other hand, the defender either exerts random amounts of effort defending all targets or gives up on all of them. In contrast, with the lottery CSF, the attacker exerts the same level of effort at every target. Although the theoretical predictions associated with the auction CSF are, on the whole, supported by the data, the last prediction of the lottery CSF is not borne out by the data. The experimental evidence shows that not only do attackers employ stochastic guerilla warfare strategies in most of the games with the auction CSF, but surprisingly, they also do so in about half of the games with the lottery CSF.

Montero et al. (2014) investigate both discrete and continuous constant-sum Colonel Blotto games where battlefields have asymmetric values and values are the same for both players. The authors systematically vary the number of battlefields, with one battlefield having higher value than the others, and the resource budgets. The objective is majoritarian, i.e., the player who accumulates the highest sum of battlefield values wins the game. The results of the experiment indicate that subjects often use strategies that allocate resources to a subset of battlefields that is the minimum necessary for winning. Moreover, within this subset, resources are allocated proportionally to the value of the battlefield, contrary to the theoretical prediction of Young (1978) that the more important battlefield should receive a disproportionally higher allocation than the less important battlefields.

Finally, Horta-Vallve and Llorente-Saguer (2010) examine a discrete Colonel Blotto game with incomplete information concerning the players' values of the individual battlefields. Players have identical budgets which they simultaneously allocate across the set of battlefields and each player's vector of battlefield values is independently drawn from a discrete distribution over positive vectors whose components sum to a fixed constant. The objective of each player is to maximize the expected sum of battlefield values won. The authors systematically vary the number of battlefields. The results of the experiment indicate that subjects do not play truthful strategies, i.e., strategies that reveal subjects' preferences for winning specific battlefields. Nevertheless, in the aggregate subjects attain more than 80% of the efficient level of welfare, i.e., the sum of the players' payoffs is maximized.

6. Extensions

6.1. Sabotage in Contests

Sabotage occurs whenever a contestant invests in reducing the effectiveness of a rival's effort. Other things constant, sabotage increases the saboteur's probability of winning. Such destructive activities typically require using scarce resources so that, in general, sabotage is a costly and welfare-reducing endeavor. As noted by Carpenter et al. (2010), despite the importance of sabotage to the efficiency properties of tournaments, relatively little experimental work has been devoted to it. Harbring and Irlenbusch and their co-authors (2005, 2007, 2008, 2011) have provided a large share of the findings in this area. Several studies show that sabotage activities increase as the spread between winner and loser prizes widens (Harbring and Irlenbusch, 2005; Falk et al., 2008; Harbring and Irlenbusch, 2011). These studies focus on the role of the contest designer (the principal) in mitigating the incidence of sabotage through the judicious choice of incentive contracts. A contest designer who seeks to maximize total effort should optimally reduce the spread between winner and loser prizes, as compared to the optimal spread when sabotage is not possible.

Gürtler et al. (2013) show theoretically that sabotage is not only counterproductive but it also imposes an indirect cost of weakening incentives. They examine a two-stage game with a simultaneous binary choice of effort in the first stage followed by a simultaneous binary choice of sabotage activities, contingent on the profile of efforts, in the second stage. In the equilibrium, leaders (those exerting high effort in the first stage) are sabotaged more than followers (those exerting low effort) and thus there is less incentive to exert the high effort required to be a leader. Gürtler et al. demonstrate that this problem can be solved by concealing intermediate information on the players' performances. These theoretical predictions are supported by complementary experimental studies.

Carpenter et al. (2010) add context and a real-effort task to the experimental study of sabotage. In their experiment, participants engage in a clerical task whose output is measured along two dimensions: quantity and quality. Participants privately evaluate each other's performance along these two dimensions. Underreporting both of quantity and quality, i.e., sabotage, is thus feasible at no monetary cost. The authors examine two compensation schemes, piece-rate and tournament, expecting that sabotage would occur only under the tournament scheme. The results are clear-cut: objectively measured output is highest under tournament incentives when sabotage is not feasible and lowest in the tournament with sabotage. The possibility of sabotage does not affect output under piece-rate incentives.

6.2. Feedback in Contests

There has been relatively little theoretical work on the impact of feedback on individual performance in contests (for exceptions, see Kräkel, 2008; Ederer, 2010). Nevertheless, there are many studies in the lab and in the field investigating how feedback impacts behavior in contests. The findings on feedback are mixed, with different studies often providing contrasting results.

Eriksson et al. (2009a) experimentally investigate the impact of feedback on individual performance under piece-rate incentive schemes and in real-effort rank-order tournaments. The three feedback conditions are: no feedback about relative performance, discrete feedback given halfway through the production period, and continuous feedback. The results of the experiment indicate that neither discrete nor continuous feedback has any effect on effort under a piece-rate scheme. In contrast, in the rank-order tournament there are some positive peer effects of feedback, with players who lag behind never quitting and players who are ahead not slacking during the contest. Similarly, Fershtman and Gneezy (2011) study how feedback impacts quitting behavior in tournaments by conducting a field experiment with high school students running athletics races. In the two treatments of interest, students either run side by side (feedback) or separately (no feedback). In contrast to Eriksson et al. (2009a), Fershtman and Gneezy (2011) find that students often quit the tournament with continuous feedback, while there is significantly less quitting with no feedback.

Kuhnen and Tymula (2012) design a real-effort tournament experiment in which subjects work on multiplication problems during a 90-second round. Kuhnen and Tymula find that subjects work harder and expect to rank better when they are told they will learn their ranking, relative to cases where they are told feedback will not be provided. After receiving feedback, subjects who ranked better than expected decrease their performance, but expect an even better rank in the future rounds. Subjects who ranked worse than expected increase their performance and lower their future rank expectations. Similarly, Ludwig and Lünser (2012) find that in a chosen-effort two-stage rank-order tournament, contestants who lag behind tend to increase effort in the second stage, while those who lead tend to reduce effort. Nevertheless, the authors find no significant difference in total effort between the feedback and the no feedback treatments. Hence, although providing feedback changes the timing of effort expenditure, it does not alter the overall performance of the tournament. In a chosen-effort lottery contest, Mago et al. (2014) also find that ex-post feedback about relative performance does not affect aggregate effort in contests, but it significantly affects the dynamics of individual behavior similar to the real-effort experiments of Ludwig and Lünser (2012) and Kuhnen and Tymula (2012).[21]

Given that feedback can sometimes have a significant effect on effort, the principal may have an incentive to misreport intermediate information to the contestants (Ederer, 2010). Ederer and Fehr (2009) design a two-stage rank-order tournament between two agents in which total output across stages is used to determine the winner. In one of the treatments, the agents are not told their first-stage output levels, while the principal learns that information. Before the second stage begins, the principal may report effort levels to each of the agents. In the treatment of

[21] An exception is Fallucchi et al. (2013) who investigate the role of information feedback in a chosen-effort lottery contest and find that additional feedback about rivals' efforts reduces aggregate effort. One notable difference is that Fallucchi et al.'s experiment lasts for 60 periods, while Mago et al.'s experiment lasts only for 20 periods.

interest, the principal's message is cheap talk and thus, should be ignored in a perfect Bayesian equilibrium. In equilibrium, even a message known to be truthful should not affect second-stage effort levels. Equipped with these predictions the authors find that subjects expend similar effort when the principal provides either no feedback or feedback that is known to be truthful. Furthermore, these effort levels are not significantly different from the equilibrium prediction. In contrast, when the principal's feedback is cheap-talk, effort is lower than in the other two treatments. Gürtler and Harbring (2010) also analyze a principal's optimal feedback policy in tournaments. They show that in equilibrium the principal reveals intermediate information regarding the agents' previous performances if these performances are relatively similar, and agents react to the principal's feedback decision. The experimental findings provide some support for the theoretical predictions of the model. Agents exert lower efforts when principals reveal intermediate information about relatively uneven performance. Principals correctly anticipate this behavior and, as a consequence, they are less likely to reveal information about agents' intermediate performance if this performance is relatively uneven.

6.3. Bias in Contests and Affirmative Action

In Section 3.2 we noted that greater heterogeneity between players may lead to lower aggregate effort in contests because of the "discouragement effect": the ability and willingness of a stronger player to bid aggressively to win the contest discourages a weaker player from bidding aggressively for fear of losing his bid. As a consequence, the weaker player reduces his effort. A contest designer wishing to maximize aggregate effort may take this effect into account and bias the contest against one or more of the candidates. This bias may be implemented either through discounting or "handicapping" the effort of stronger players or through augmenting the efforts of weaker players.

The primary application of the study of bias in contests is to the examination of affirmative action policies in hiring or education. Although there are many motivations for inducing bias in contests, our focus here is that bias may in fact induce greater aggregate effort in equilibrium.[22]

One of the first laboratory studies on affirmative action is Schotter and Weigelt (1992). Without affirmative action, Schotter and Weigelt find that disadvantaged players usually drop out of rank-order tournaments. However, this discouragement effect decreases when affirmative action, designed as a head-start advantage for the disadvantaged player, is implemented. As a result, the aggregate performance in the tournament increases, although the magnitude of this effect depends on the degree of heterogeneity and the level of affirmative action.

Michelitch (2009) points out a potential disadvantage of affirmative action policies such as quotas, i.e., dividing the set of all contestants into subsets that compete for separate sets of prizes. A common criticism is that quota-eligible individuals exert less effort in a tournament, while quota-ineligible individuals exert more effort. In a tournament experiment, Michelitch (2009) finds that quota-eligible individuals indeed exert less effort than quota-ineligible individuals. Balafoutas and Sutter (2012) and Niederle et al. (2013) examine how affirmative action affects competitive entry and performance in tournaments by men and women. Niederle et al. (2013) find that, although affirmative action (towards women) encourages entry by women into tournaments, it may come at the cost of discouraging entry by men. Balafoutas and Sutter (2012) find that affirmative action leads to significantly higher entry by women; however, it does

[22] Filippin and Guala (2013) show that subjects in the role of a principal choose to discriminate in favor of their in-group members even when all contestants are symmetric and exert the same efforts.

not discourage entry by men. Moreover, affirmative action leads to higher aggregate performance in tournaments.

Finally, Calsamiglia et al. (2013) use a field experiment to study affirmative action policies among children. As in the two studies mentioned above, they find that an affirmative action policy significantly increases the chance of disadvantaged players winning the tournament, without discouraging the performance of other players. We discuss the study of Calsamiglia et al. (2013) in more detail in Section 7.

6.4. Collusion and Communication

In the three contest formats discussed in this paper, players could increase their total expected payoffs by jointly lowering their individual efforts below the Nash equilibrium level. Clearly, the total expected payoffs are maximized when all contestants expend zero effort (with a suitable tie-break). Therefore, there is a strong incentive for collusion among participants. Although collusion does not seem relevant in some of the applications of contest theory (e.g., political competition), in other cases, it is a real possibility (e.g., military conflict, labor tournaments, R&D competition).

The study of collusion in experimental contests is even more important given that subjects tend to overbid. Imperfectly collusive behavior may in fact bring effort levels closer to the static non-cooperative equilibrium levels. For the all-pay auction, Lugovskyy et al. (2010) find that this is indeed the case in comparing behavior under random matching to behavior under fixed matching. Although the number of periods is known, thereby making the game a finitely repeated game, bids are lower with fixed matching than with random matching. In a multiple-prize discrete all-pay auction, Harbring and Irlenbusch (2003) vary the number of contestants from two to six and employ fixed matching. They find that effort levels are lower in two-player than in six-player contests because a greater fraction of players bid zero. Such seemingly collusive behavior is significantly less frequent with a greater number of contestants.[23]

Even with repeated interactions, collusion may be difficult to sustain if it remains tacit. Therefore, it is crucial to analyze the impact of communication on effort levels. Harbring (2006) compares the total effort in a standard two-player rank-order tournament setting with a winner and a loser prize to a non-competitive team compensation scheme where total output is shared equally between the two players. The design varies the compensation scheme, whether or not communication is possible between contestants and the type of communication. In one of the communication treatments, the contestants are restricted to messages about their intended actions. In another communication treatment, the contestants may use a chat program. All sessions use a fixed matching protocol. Harbring finds that although restricted communication only has a weakly collusive effect on effort, chat communication increases effort under the team compensation scheme and dramatically lowers effort under tournament incentives. Both findings suggest a strong effect of communication on cooperative play.

Sutter and Strassmair (2009) and Cason et al. (2012) compare the effect of communication between groups of players to communication within a group of players. Communication is implemented using a chat application. Both studies find that simple within-group communication leads to higher effort, but not necessarily to higher earnings (Cason et al., 2012, 2014).[24] On the other hand, extending communication opportunities to allow both for

[23] In a related experiment with sabotage, Harbring and Irlenbusch (2008) fail to replicate the finding that two-player contests are prone to collusive behavior.

[24] In a related study, Leibbrandt and Saaksvuori (2012) document similar results in contests between groups.

within and between-group communication helps collusion by lowering effort levels and thus raising average earnings.

6.5 Group Contests and Alliances

Many contests are characterized by competition between groups (or "teams" or "alliances") and not individuals. Examples include competition between corporate consortia, R&D competition between firms, election campaigns by political parties and alliances between countries engaged in warfare. The formation and performance of alliances in conflicts is a topic as old as the study of conflict and much of the recent modeling in this area has employed contest theory (for a survey, see Bloch 2012). The renewed theoretical interest in alliances has seen a parallel interest in experiments on group and alliance behavior.

In group contests, members of the same group have an incentive to cooperate with each other by contributing individual efforts in order to win the contest. Since effort is costly, each member also has an incentive to shirk in contributing effort and free-ride on the efforts of other members. Theoretically, the amount of free-riding that occurs within a group depends on the composition of the group, the technologies of group performance, and the rules that regulate the competition (Baik, 1993; Lee, 2012; Chowdhury et al., 2013b).

Much of the experimental literature on group contests is recent and employs the lottery CSF. Some of the studies focus primarily on the performance of groups assuming that the prize is shared equally among group members (e.g., Abbink et al., 2010; Sheremeta and Zhang, 2010; Cason et al., 2012, 2014). A distinct set of experiments examine the role played by the sharing rule within the winning group (e.g. Ke, 2011; Ke et al., 2012, 2013). The sharing rules that are compared are equal sharing, sharing proportional to individual effort and nested contests, whereby the members of the victorious alliance engage in a within-group contest.

Abbink et al. (2010, 2012) and Ahn et al. (2011) study lottery contests between symmetric groups as in Katz et al. (1990), where each winning group member receives the full prize. They investigate treatments in which individuals compete, respectively, against individuals and against groups. All three studies document very high rates of overbidding, with the highest bids reaching up to five times the Nash equilibrium level. This overbidding is observed in all treatments, regardless of whether individuals compete against individuals, groups compete against groups, or individuals compete against groups. Abbink et al. (2010) further document that when group members are allowed to punish free-riders, the overbidding is even higher (up to nine times higher than the Nash equilibrium). Such high rates of overbidding are troubling and are hard to reconcile with standard economic theory. Abbink et al. (2012) suggest that such behavior in intra-group contests can be explained by parochial altruism – altruism towards group members along with hostility towards non-members.

Cherry and Cotten (2011) extend the theoretical analysis of Katz et al. (1990) by introducing the possibility that the two competing groups may be interdependent (i.e., individuals can be part of both sides of a contest). Theoretical and experimental results indicate that strategic individual behavior, and the resulting rent dissipation, is affected by the relative size of the groups. Specifically, Cherry and Cotten (2011) find that individual efforts by group members decrease and individual efforts of those outside the group increase in the relative size of the group. These results are consistent with one of the Nash equilibria of the group contest with interdependent groups.

Sheremeta and Zhang (2010) study lottery contests between teams, each comprised of two players who must decide upon a single team effort, and compare team effort to the effort in a properly normalized contest between two (single) players. The team members can communicate before the contest. Although single players and teams over-expend effort compared to the predicted levels, teams perform better by exerting efforts that are closer to Nash equilibrium. One interpretation of this finding is that alliances can make better decisions than individuals. Deck et al. (2012) examine alliances in a model in which an attacker selects among two targets after observing the level of defense at each. The attacker attacks the weakest target, meaning that if each target is defended separately, one defender's expenditure imposes a negative externality on the other. Deck et al. examine experimentally whether this externality provides an incentive for the defenders to form an alliance and the alliance's impact on equilibrium expenditures. One implication of the model is that if the defenders form an alliance then their expected payoffs increase despite the fact that a successful attack is more likely given the overall reduction in defense. Experimentally, alliances yield higher payoffs to defenders as predicted, but also reduce the likelihood of a successful attack, counter to the theoretical prediction.

So far, all of the contests between groups discussed share the feature that all players within the winning group split the prize equally. Such an egalitarian sharing rule creates incentives for some group members to free-ride on the effort of others. One possible solution is a proportional sharing rule, where players of the winning group split the prize in proportion to the efforts that they contributed to the group performance. Gunnthorsdottir and Rapoport (2006) and Kugler et al. (2010) find that the proportional sharing rule elicits higher individual efforts than the egalitarian rule.

The experimental literature on alliances in conflicts further emphasizes the role played by the sharing rule within the alliance. Ke et al. (2013) consider a setting in which an alliance of two players fights a single opponent in a lottery contest, with the sharing rule as the key treatment variable. In one treatment, the members of a victorious alliance share the prize equally. In the other treatment, they engage in a within-alliance lottery contest in order to determine which alliance member earns the prize. In the latter case, the contest is a two-stage game. Ke et al. emphasize their comparison of within-alliance contests to contests between two strangers. Theory predicts that there should be no difference in behavior when the contest is between fellow group members as compared to a contest between strangers. The data provide evidence for this prediction. However, there is no evidence in favor of the hypothesis that an exogenously given equal sharing rule results in higher alliance effort than the contest sharing rule. In a related study, Ke et al. (2012) find that alliances are more likely to break down if the sharing rule is not the equal sharing rule. Finally, Ke (2011) finds that when allies share the prize proportionally (as in the deterministic proportional-prize contest), instead of probabilistically (as in the lottery contest), efforts are significantly lower by both allies and stand-alone opponents, resulting in higher payoffs to all competing parties. Therefore, Ke (2011) finds that alliance formation can be beneficial to both allies and stand-alone players.

Behavior in group contests with an auction CSF has been examined experimentally by Amaldoss et al. (2000), although they specify that no player wins a prize in the event of a tie. They consider contests played by teams of two players. Each alliance's pure strategy space has three possible effort levels, including zero. In one of the treatments, the alliance's effort is the maximum of its members' efforts (best-shot), whereas in other treatments the alliance's effort is the sum of the efforts of its members (perfect substitutes). The authors consider two sharing rules for the victorious alliance: equal sharing and sharing that is proportional to effort (as in the deterministic proportional-prize contest). Finally, the authors vary the size of the prize across treatments. For both types of alliances (best-shot and perfect substitutes), regardless of the sharing rule, the mixed strategy equilibrium explains aggregate frequencies of play reasonably well for high and medium prizes. However, when the prize value is low, subjects tend to overbid relative to the Nash equilibrium. The sharing rule has no significant effect on effort. The key finding is that best-shot contests generate significantly less effort than alliances in which effective effort is the sum of the members' expenditure. This behavior is consistent with the equilibrium prediction.

The experimental analysis of rank-order tournaments between groups began almost two decades ago with Nalbantian and Schotter (1997). In their experiment, there are two identical groups, consisting of six players each, and the performance of the group is the sum of all the individual group members' efforts. The best performing group receives the prize and all players of the winning group split the prize equally. Nalbantian and Schotter (1997) find that, compared to other incentive schemes (i.e., profit sharing, revenue sharing, or gain sharing), a contest between groups increases effort and mitigates the within-group free-rider problem. Similar qualitative results are obtained in an information gathering experiment by Vasilaky (2011) and a real-effort experiment by van Dijk et al. (2001). Follow-up studies by Sutter and Strassmair (2009), Cason et al. (2012, 2014), and Leibbrandt and Saaksvuori (2012) show that the introduction of within-group communication can further reduce the free-riding incentives within a group. However, as pointed out by Cason et al. (2012), enhanced within-group coordination may lead to extensive and inefficient competition between groups.

We end this section with a brief discussion of natural extensions to heterogeneous players and endogenous alliance formation. Most studies on contests between groups assume identical players within each group. One notable exception is Sheremeta (2011b), who investigates lottery contests between groups, where each group has one strong player, with a higher valuation for the prize, and two weak players, with lower valuations. The experiment examines three contests: a perfect-substitutes contest in which all efforts are perfect substitutes (Baik, 1993), a best-shot contest in which group performance depends on the best performer (Chowdhury et al., 2013b), and a weakest-link contest in which group performance depends on the worst performer (Lee, 2012). Sheremeta finds that in perfect-substitutes contests all players expend significantly higher efforts than predicted by theory. In best-shot contests, most of the effort is expended by strong players while weak players free-ride. Finally, in weakest-link contests, there is almost no free-riding and all players expend similar positive efforts.

The endogenous formation of alliances is examined by Herbst et al. (2012). Their experiment implements three-player lottery contests with random matching. In a two-by-two design they vary whether alliance formation is exogenous or endogenous, as well as the cost of forming an alliance (in one of the treatments, this cost is negative so that alliance formation is subsidized). Herbst et al. find that contestants who expend relatively lower effort levels in contests where no alliance is formed display a greater willingness to form alliances. Despite this observed self-selection of less aggressive subjects into alliances, endogenous alliances tend to generate higher effort than exogenously formed alliances.

6.6. Behavior and Gender

A number of contributions to the literature examine whether men and women behave differently in contests and tournaments. Gneezy et al. (2003) point out that the answer to this question is of great economic importance because tournaments are ubiquitous within firms, especially among top management. Furthermore, gender differences in many aspects of human activity have been a subject of study across a wide array of disciplines, ranging from biology to psychology (Gneezy and Rustichini, 2004). Economists have much to contribute to this large body of literature, in particular through the use of experimental methods.

Several experimental studies do indeed find robust evidence that men and women behave differently in tournaments (Croson and Gneezy, 2009; Niederle and Vesterlund, 2011). In fact, this evidence is corroborated both by laboratory and field experiments. Generally speaking, women are less likely to enter tournaments than men are (women "shy away from competition"). Second, women do not perform as well as men under tournament incentives. Third, possible differences in attitudes toward risk can only partially explain these differences. An extensive survey of gender differences is already available (Niederle and Vesterlund, 2011) and is beyond the scope of this paper. Therefore, we simply highlight a handful of major contributions and some of their extensions.

When studying gender related questions, laboratory experiments that use a real-effort task such as adding sequences of numbers or maze solving are common. Gneezy et al. (2003) have groups of men and women engage in a maze solving task. They find that women perform as well as men under a piece-rate scheme, but they solve significantly fewer mazes under tournament incentives. They are able to rule out differences in risk aversion as the factor causing the discrepancy and, instead, they argue that differing attitudes toward competition play a major role.

Gneezy and Rustichini (2004) use a field setting wherein pairs of schoolboys and schoolgirls compete in a footrace, first in a non-competitive and then in a competitive environment. When competing, children of equal ability are matched in pairs. In this pure field experiment, there are no monetary incentives. The general finding is that, when compared to a non-competitive setting, under competition boys improve in their performance relative to girls. In fact, as in Gneezy et al. (2003), when a girl is matched with a boy, a girl's performance tends to be lower in the competitive race than when there is no competition.

Niederle and Vesterlund (2007) design an experiment that focuses on selection into tournaments. The subjects engage in a number adding task under both piece-rate and tournament incentives. While the performances of men and women are not statistically different under either the piece-rate or tournament schemes, when asked which payment scheme they would like to participate in, men choose the tournament much more often than women. The authors attribute this result to gender differences in confidence and attitudes toward competition. We note that their study spearheaded a host of papers on the topic, most of which replicate their result (e.g., Cason et al., 2010; Niederle and Vesterlund, 2011; Balafoutas and Sutter, 2012). Notably, in a setting similar to Niederle and Vesterlund (2007), Healy and Pate (2010) find that competition in teams helps close the gender gap in entry by two thirds.

Interestingly, several studies (Mago et al., 2013; Brookins and Ryvkin, 2014; Price and Sheremeta, 2014) find that women bid significantly more than men in lottery contests.[25] As a result of significantly higher bids, women receive significantly lower earnings from the contest than men. The fact that women earn significantly lower payoffs in contests may suggest that the ex-ante decision to "shy away from competition" may be rational.

[25] Similarly, Ong and Chen (2012) find that women bid significantly more than men in all-pay auctions with complete information. Moreover, controlling for the gender of the bidder and the opponent, Ong and Chen argue that observed behavior is consistent with equilibrium behavior where women attach a higher valuation to winning the all-pay auction than men.

7. Field Experiments

Field experiments differ from their laboratory counterparts in many respects (Harrison and List, 2004). Not only do field experiments use real-effort tasks, but these tasks are performed in their natural environment by professionals (experts).

Erev et al.'s (1993) orange grove experiment is arguably the first experiment to test contest theory in the field. The focus of the study is on the incentives to free-ride in teams of fruit pickers. The authors view effort contribution to the team as a voluntary contribution mechanism (VCM). Hence, if each team member is paid an equal share of the team's output, free-riding is an equilibrium strategy. In one of the treatments, the teams of four workers are split into pairs that compete against each other for a reward. The within-team contest should provide an incentive for each pair to contribute effort and thus avoid free-riding. Erev et al. find that tournament incentives lead to significantly higher output (a 35% gain). Furthermore, output tends to increase over time in the contest treatment, while it tends to fall in the VCM condition, so tournament incentives help teams overcome the free-riding problem. Blimpo (2014) and Bigoni et al. (2011) replicate this result in the setting of secondary schools in Benin and the University of Bologna in Italy, suggesting that tournaments can be effective mechanisms in increasing team performance and school achievement.

Leuven et al. (2011), conduct a field experiment using students at the University of Amsterdam in the Netherlands. Students could self-select into tournaments with one of three types of prizes: low (€1000), medium (€3000) and high (€5000). In the data, performance increases with the size of the prize, but the authors show that this positive effect of tournament incentives is due to sorting. Controlling for sorting and heterogeneity of students, there is no significant effect of tournament incentives on the aggregate performance of students. Similarly, very little in the way of incentive effects are documented by Leuven et al. (2010). One possible reason for the insignificant findings in both of these studies is that the ratio of the number of prizes to the number of students is very low (i.e., less than 1 to 25). De Paola et al. (2012) conduct a field experiment, involving undergraduates at a university in southern Italy, where the number of prizes to the number of students is relatively high (i.e., around 1 to 5). Students are randomly assigned to one of the three treatments: a control group, a small prize (€250) and a large prize (€700). They find that, as predicted by theory, more valuable prizes significantly increase student performance both in terms of the number of credits earned and the grades obtained on exams. High ability students, who are very likely to win the tournament, increase their performance the most, while low ability students do not change their performance.

Hossain et al. (2014) conduct a field experiment at a large-sized Chinese manufacturing company. During the eight-week long experiment, workers on the team with the higher per-hour productivity were provided a weekly prize (bonus). The prize was framed either positively as a reward or negatively as a punishment (although both framings are theoretically equivalent). Prizes increased the average weekly productivity by 14%, indicating a strong incentive effect of tournaments. Moreover, the team for which prize was framed as a punishment was at least 35% more likely to produce at a rate higher than the team for which prize was framed as a reward.

Delfgaauw et al. (2013) find that tournament incentives have a significant effect on sales performance. They implement a sales competition between grocery stores belonging to the same retail chain. The rank-order tournament between stores is based on sales growth as the performance measure. There are two treatments, one in which two winner prizes are awarded to the two top performers and one in which there is no prize. In the latter treatment, stores simply provide feedback on relative performance. In the data, sales growth is higher in both treatments than in the baseline without relative performance information. Surprisingly, simple feedback is as effective in increasing sales growth as the monetary reward.

Fershtman and Gneezy (2011) also highlight the importance of feedback in tournaments. They design a field experiment involving schoolchildren who participate in a 60-meter footrace. The design varies matching (assortative by skill versus random), the power of tournament incentives (none, low, high) and the information condition (contestants either run side by side or on separate tracks). The main finding is that the likelihood a contestant will give up during the race is highest in the high reward treatment. Hence, high-reward tournaments seem to induce more "quitting in the middle," particularly when contestants run side by side. By contrast, such quitting behavior barely occurs under low or no reward. Another finding is that tournaments with no reward draw little participation. That is, a significantly larger number of students opt out of the tournament race when no reward is offered than in the other treatments. Finally, the authors conclude that the overall winner of the race performs better in the high reward treatment than with either no or a small reward.

Field experiments have also been used to study different predictions from contest theory. Calsamiglia et al. (2013), for example, design pair-wise tournaments among children from two schools in Spain. Students in one school (experienced) are taught how to solve simple numerical puzzles or "sudokus" as part of their regular mathematics courses, while students in the other school (inexperienced) are not. In the experiment, students from the two schools competed in pair-wise tournaments for 30 minutes by solving sudokus. The findings confirm that the asymmetry in experience is reflected in subjects' performance, with experienced subjects solving significantly more than inexperienced subjects. A policy which marginally biases tournament rules in favor of inexperienced students reduces performance of experienced subjects, while significantly increasing the chances of inexperienced subjects to win the tournament.

List et al. (2014) conduct both a laboratory and a field experiment to study how the number of contestants impacts individual efforts in tournaments. The field experiment uses non-professional fishermen as subjects. One of the notable characteristics of the experimental setting is that it allows the authors to measure inputs, while most field studies on tournaments only measure output (they demonstrate empirically that the input measure has a large and significant effect on fish caught). The design varies the number of contestants between two and eight within session. The authors argue that because the stock of fish in the pond decreases with each catch, the density of the noise is decreasing. In this case, effort is predicted to decrease with the number of contestants (see a more detailed discussion in Section 3.1). Experimental data provide strong support for this prediction. Casas-Arce and Martinez-Jerez (2009) analyze the sales contests organized by a commodities firm and, similarly to List et al., find that individual efforts decrease in the number of contestants.

Another design issue in tournaments is the number of prizes (see Sections 3.3 and 3.4). Lim et al. (2009) conduct a field experiment among salespeople which is also accompanied by a chosen-effort experiment (for details see Section 8). In the experiment, salespeople were asked to either sell sponsorships to the business community through a golf tournament or to solicit donations from companies to raise funds for the university. Salespeople were assigned either to a 15-salespeople contest with one prize of $300 or to a 15-salespeople contest with five prizes of $60. Consistent with the theoretical predictions of Kalra and Shi (2001), the authors find that the five-prize contest elicits higher performance (average sales) than the equivalent single-prize contest.

Many tournaments in the field have a dynamic structure (see Section 4). Liu et al. (2014) design a field experiment to study the performance of sequential and simultaneous all-pay auctions with incomplete information. The experiment is conducted on a crowdsourcing website Taskcn.com, one of the largest Q&A sites in China. Consistent with theoretical predictions, tasks with high prizes attract more submissions and higher quality answers than tasks with low prizes. Also, as expected, in the sequential case early entry of a high quality answer deters the entry of users. Delfgaauw et al. (2014) conduct a field experiment in a retail chain to test basic predictions regarding the prize spread and noise in two-stage elimination tournaments. Tournaments differ in the distribution of prize money across the respective winners of the first and second stages of the tournament, while keeping total prize money constant. The modified model of Lazear and Rosen (1981) predicts that a more convex prize structure leads to better second-stage performance at the expense of first-stage performance. It also predicts that noise weakens incentives to perform, as it reduces the marginal effect of effort on the probability of winning. The findings indicate that, as predicted by theory, a more convex prize spread increases performance in the second stage at the expense of first-stage performance. Noise also has a negative effect on the response to tournament incentives.

There are several field experiments that compare tournaments with alternative payment schemes. Bandiera et al. (2005) exploit an exogenous change in the compensation scheme of workers at a large farm to compare piece-rate and relative performance pay. Under the relative performance pay, workers are paid according to how their productivity compares to average productivity in the field; thus, a worker's expected payoff is similar to the expected payoff in a lottery contest. The main finding of interest is that for the average worker, productivity increases by at least 50% when moving from tournament-type incentives to a piece-rate scheme. The authors conclude that workers behave as if they have social preferences and are thus reluctant to impose negative externalities on other workers by exerting higher effort in tournaments. In the follow up study, Bandiera et al. (2006) find substantial evidence of collusive behavior in tournaments, which can further explain why piece-rates may sometimes outperform tournaments. In the same line of research, Bandiera et al. (2013) design a field experiment to evaluate the effects of piece-rate, tournament and rank incentives (i.e., simply displaying the rank of each team's productivity) on the productivity and composition of teams. They find that the introduction of tournament and rank incentives leads to significant changes in team composition, making workers more likely to form teams with others of similar ability instead of with their friends. Introducing rank incentives reduces average productivity by 14%, whereas introducing a tournament increases it by 24%. However, the effects are heterogeneous: rank incentives only reduce the productivity of low ability teams, and tournaments only increase the productivity of high ability teams. Finally, teams that remain intact after the introduction of incentives do not change their productivity under rank incentives but increase their productivity by 25% under tournament incentives. In summary, these findings suggest that tournaments affect firm performance through both the endogenous changes in team composition and changes in behavior within the same team.

Finally, several studies show how tournaments with no monetary prizes can be used as incentive mechanisms in the field (Kosfeld and Neckermann, 2011; Barankay, 2011).[26] Kosfeld and Neckermann (2011), for example, design an experiment to study how symbolic awards impact individual behavior in the field. In the experiment, students enter data for three weeks as

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[26] For a laboratory experiment on tournaments used as an intrinsic motivation for giving see Duffy and Kornienko (2010). Also, see Sheremeta (2010a, 2010b).

part of a non-governmental organization project. The treatment is to honor the best performance publically with a symbolic award. Kosfeld and Neckermann find that the award treatment raises performance by 12%. Barankay (2011) designs a field experiment on a crowdsourcing website to see how feedback about ranking (in terms of performance compared to others) affects the behavior of employees. Although rank has no real implication for compensation, compared to a control group with no rank feedback, employees who receive feedback about their rank are 30% less likely to return to work and also 22% less productive on the job. Although the studies of Kosfeld and Neckermann (2011) and Barankay (2011) are not directly comparable, the striking difference between their findings further highlights the importance of conducting field experiments.

8. Applications

Contest theory may be used to examine a wide range of topics, from sports competitions and the competition for admission to college, to political campaigns, innovation races, and military conflict. Arguably one of the most direct applications of contest theory is to political competition and lobbying. Tullock's (1980) seminal work that introduced the canonical Tullock contest is an analysis of rent-seeking behavior. Moreover, in the United States in particular, elections resemble contests in which candidates spend effort and money on advertising in order to increase their chance of winning. Hence contest theory naturally applies to electoral competition. Beginning with Millner and Pratt (1989) and Davis and Reilly (1998), a number of experimental studies have examined behavior in political contests. For example, Öncüler and Croson (2005) study a political contest in which the value of the prize is uncertain at the time candidates commit to campaign expenditure. Bullock and Rutström's (2007) experiment also considers an environment where lobbyists compete for a prize of endogenous value. Kräkel et al. (2012) examine behavior in a two-player electoral contest, where candidates first decide on their political program (high or low risk) and then spend money (exert effort) conveying these programs. Other experiments on political competition include Sheremeta (2010a), who studies an elimination political contest with effort carryover, and Irfanoglu et al. (2014), who analyze a best-of-three contest designed to gain insight into the so-called New Hampshire effect (Klumpp and Polborn, 2006). These studies are discussed in more detail in Section 4.4 and Sections 5.2.

Theoretical models of contests have also been used to analyze expenditure on legal services in litigation. In this context, the players are litigants and their bids represent expenditures on legal services. The contest success function is interpreted as a production function of legal outcomes. Several experimental studies have applied contest models to legal battles in order to compare the effect of different fee allocation rules on legal expenditure. Coughlan and Plott's (1997) experiment compares the American rule to the British rule of allocating expenditure. As predicted, conditional on the occurrence of a trial, the British rule generates substantially greater total expenditure than the American rule. Dechenaux and Mancini (2008) obtain similar findings by employing the generalized contest payoff function in (5) and the auction CSF. Finally, Deck and Farmer (2009) also study the behavior of litigants with respect to expenditure on legal services, but their focus is on final-offer arbitration.

Many contest models have been employed to analyze strategic behavior in wars. Arguably, one of the first war applications of contest theory is the Colonel Blotto game introduced by Borel (1921). The two most relevant studies that investigate the behavior of attackers and defenders in war games are Kovenock et al. (2010) and Deck and Sheremeta (2012). Both studies examine behavior in (simultaneous and sequential, respectively) attacker-defender games, where the defender needs to win all targets, while the attacker needs to win only one target to secure the prize. Other experiments on war contests are done by Linster et al. (2001), who examine the incentive to invest in military deterrence faced by two members of a coalition fighting a common opponent, Lacomba et al. (2014), who examine behavior in different post-conflict scenarios, Durham et al. (1998), who study the "Paradox of Power", and Holt et al. (2014), who study the "Paradox of Misaligned Profiling."

Given the high costs of conflict documented by experimental studies, a natural question that arises is how one could avoid a potential conflict. Since the seminal book by Schelling (1960), a number of mechanisms for avoiding conflicts have been proposed, ranging from deterrence via extensive armament to contractually binding side-payments. Recently, several laboratory experiments have examined different conflict resolution mechanisms including side-payments (Kimbrough and Sheremeta, 2013, 2014) and random devices (Kimbrough et al., 2013, 2014). Other studies investigate the importance of retaliation (Lacomba et al., 2014), emotions (Bolle et al., 2014), and the length of the conflict (McBride and Skaperdas, 2012), on the likelihood of conflict avoidance.

It is important to emphasize that contests are not always destructive. For example, contests are commonly used to motivate sales. According to Lim et al. (2009), sales contests are "short-term incentives that managers use to raise sales effort." Lim et al. (2009) design both a lab and a field experiment to examine the optimal prize structure for generating the highest sales effort. A follow up study by Lim (2010) addresses the role of social preferences in influencing behavior in rank-order sales tournaments. Finally, Chen et al. (2011) study the role of asymmetries in sales contests.

Finally, contests are often used as fundraising mechanisms. There has been a recent surge in both laboratory and field experiments on fundraising contests. A number of lab experiments compare lotteries and all-pay auctions to the system of voluntary contributions (Morgan and Sefton, 2000; Lange et al., 2007; Orzen, 2008; Corazzini et al., 2010), and different types of winner-pay auctions (Davis et al., 2006; Schram and Onderstal, 2009).[27] There are also some studies that take experimental charity contests to the field: Landry et al. (2006), Carpenter et al. (2008), and Onderstal et al. (2011). The findings from these experiments point that, under certain conditions, lotteries and all-pay auctions may outperform other types of fundraising mechanisms.

9. Conclusions and Future Directions

There are several important lessons that emerge from the papers that we surveyed. First, most laboratory studies on lottery contests and all-pay auctions find significant overbidding relative to the Nash equilibrium prediction. Second, in contrast to lottery contests and all-pay auctions, there is very little overbidding in rank-order tournaments and aggregate effort usually conforms to the theoretical predictions. Third, in all three canonical contests there is significant heterogeneity in the behavior of individual subjects. Fourth, in lottery contests and rank-order tournaments bids are usually distributed around the equilibrium, while in all-pay auctions the distribution of bids is bimodal, with some subjects submitting very low and others submitting very high bids. Finally, most of the experimental studies, both in the laboratory and in the field, find support for the comparative statics predictions of contest theory. Some commonly supported comparative statics results are the impact of incomplete information on individual behavior, the

[27] Dickinson and Isaac (1998) and Dickinson (2001) were the first to show the effectiveness of an all-pay auction as an incentive mechanism in raising contributions to public goods. Although, these studies do not explicitly use the term "all-pay auction," the incentives are such that the highest contributor to the VCM receives a prize.

"discouragement effect", and the impact of contest parameters (e.g., the number of players and the number of prizes) on effort.

We see a number of fruitful avenues for future experimental research on contests. First, the sources of overbidding in lottery contests and all-pay auctions is still an open question. Although there are numerous factors that may contribute to overbidding, as discussed by Sheremeta (2013), it remains an open question as to whether some of these factors are related to each other and which are the most important. For example, is it possible that the non-monetary utility of winning is driven by status-seeking preferences, or vice versa? Similarly, judgmental biases may be correlated with mistakes and loss-aversion. It would also be interesting to examine whether the patterns of overbidding in lottery contests and all-pay auctions are caused by the same underlying attributes. For example, do the same subjects who overbid in lottery contests also overbid in all-pay auctions? If subjects make mistakes in lottery contests then does it imply that they are also more likely to make mistakes in all-pay auctions? The answers to these questions would significantly advance our understanding of overbidding phenomenon.

Second, it is intriguing that there is almost no overbidding in rank-order tournaments. Our main conjecture is that this striking difference when compared to lottery contests and all-pay auctions can be explained by the fact that in rank-order tournaments, the cost of effort is generally taken to be strictly convex (which is needed to guarantee that a pure strategy Nash equilibrium exists), contrary to the linear cost function employed in experiments on lottery contests and all-pay auctions. In fact, two studies suggest that this could be indeed the case. Chowdhury et al. (2014) find that overbidding in lottery contests significantly decreases when the cost of effort is convex instead of linear. Similarly, Müller and Schotter (2010) find that overbidding in all-pay auctions vanishes when the cost function is strictly convex instead of linear. Therefore, we conjecture that there is no overbidding in rank-order tournaments because in all experiments the cost of effort is convex. However, more research is needed to confirm this conjecture.[28]

Third, given the prevalence of overbidding in lottery contests and all-pay auctions and its absence in rank-order tournaments, it is important to know whether overbidding occurs in field settings with real-effort and high stakes. Do field experiments offer insights on whether overbidding is a robust phenomenon? If so, then are the explanations for overbidding in the field similar to the explanations for overbidding in the laboratory? Although these questions are very important, we see a number of difficulties in attempting to answer them. To examine whether overbidding is observed in the field, one needs to precisely measure individual effort. However, in the field, only the performance of contestants, which is a function of effort, ability and luck (Ericsson and Charness, 1994) is observed. Therefore, to answer the aforementioned questions, one would need to design an experiment which clearly measures individual ability and luck.

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[28] Another explanation for the lack of overbidding in rank-order tournaments is the high dispersion of the performance noise ε_i. The substantial amount of noise in the CSF may lead subjects to restrain effort, thereby decreasing overbidding. In fact, Nieken (2010) finds that when given the choice between two distributions of performance noise, subjects are reluctant to choose the distribution with the higher variance even when a risk neutral player would find it beneficial to do so. This finding confirms our conjecture that aversion to random shocks in the CSF could help explain the absence of overbidding in rank-order tournaments. Finally, the lack of overbidding in rank-order tournaments can be driven by the fact that the marginal benefit of effort around 0 is very low. In a lottery contest or an all-pay auction it is virtually impossible to win with the effort of 0, but in a rank-order tournament it is possible. Whether it is the convexity of costs, the presence of noise in the CSF, or the low marginal benefit of effort that mitigates overbidding in rank-order tournaments is an interesting question for future research.

Finally, we have only hinted at the importance of developing and investigating mechanisms aimed at avoiding potential conflicts. Although there is substantial theoretical work, originating with Schelling (1960), which addresses conflict resolution mechanisms, there are only a few experimental studies that test such mechanisms. We expect future experimental research to focus on issues such as de-escalation, deterrence, as well as the management and resolution of conflicts.

There are undoubtedly many other important applications of contest theory that have escaped our overview and will capture the interest of experimenters in the future. We very much look forward to revisiting the area in five years to see where the growth of the field, so evident in Figure 1, takes us.

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Figures

Figure 1: Time Trend of Papers Published in Academic Journals.

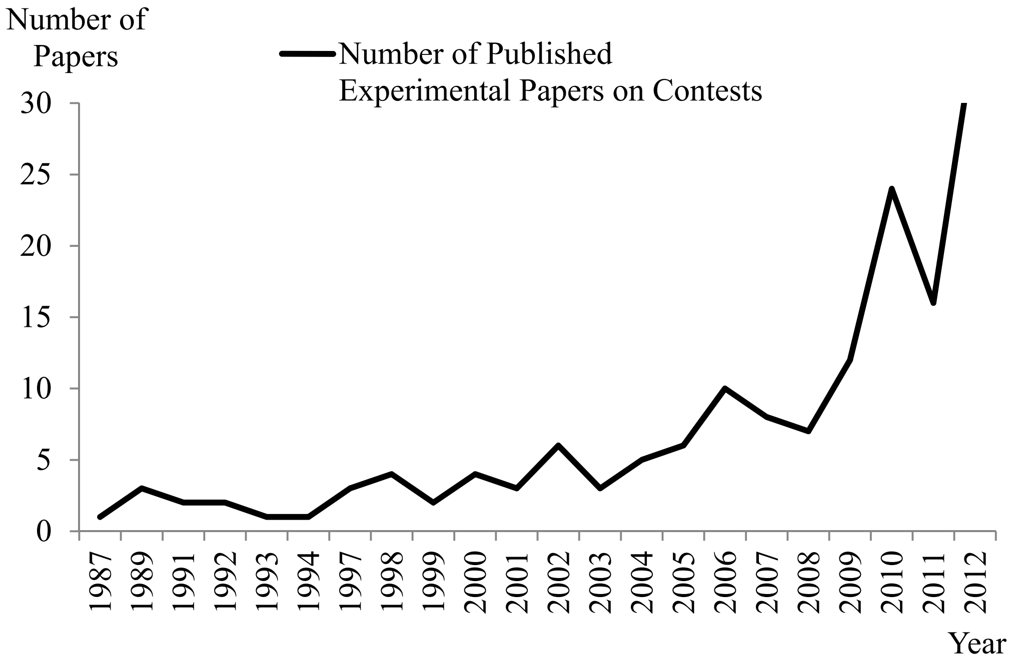
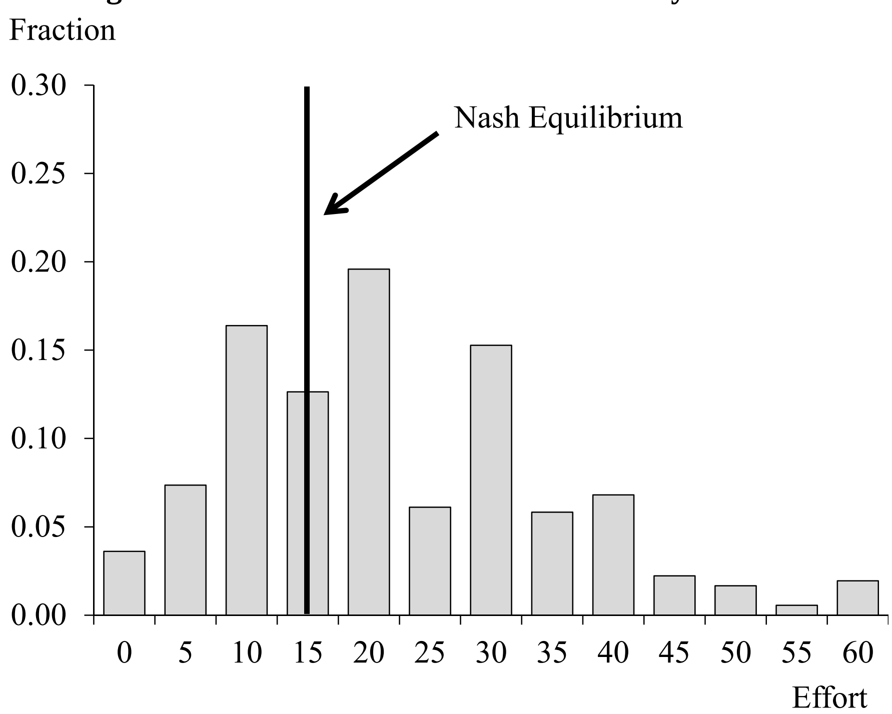
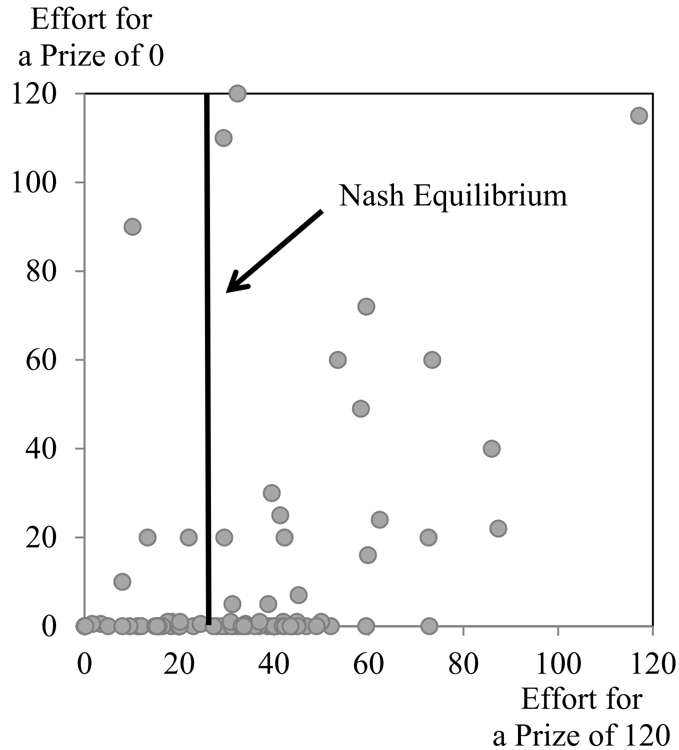


Figure 2: Distribution of Efforts in a Lottery Contest.



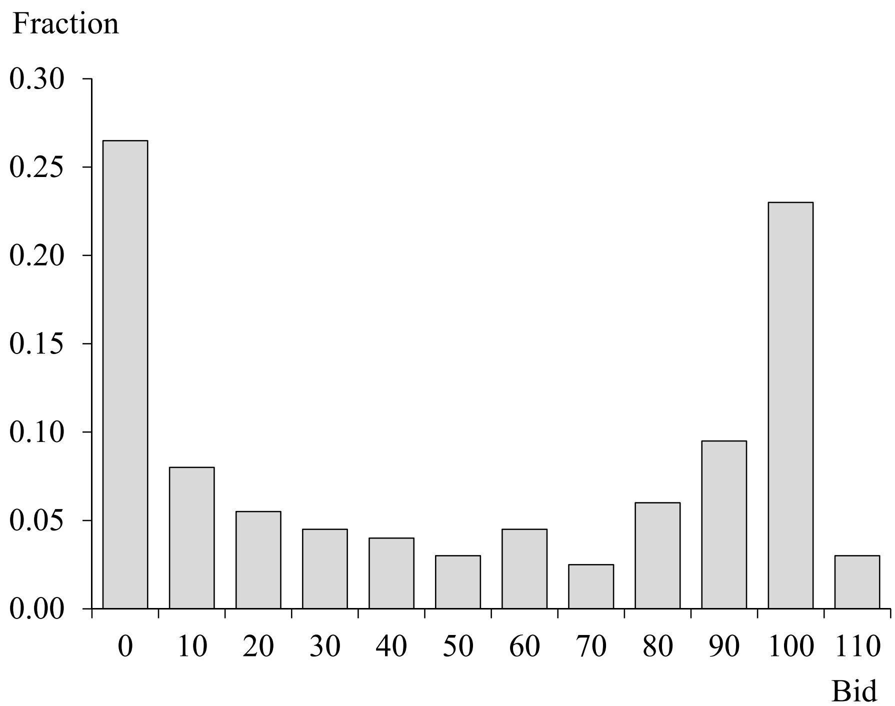
Note: The data are taken from Sheremeta (2011a).

Figure 3: Non-Monetary Utility from Winning.



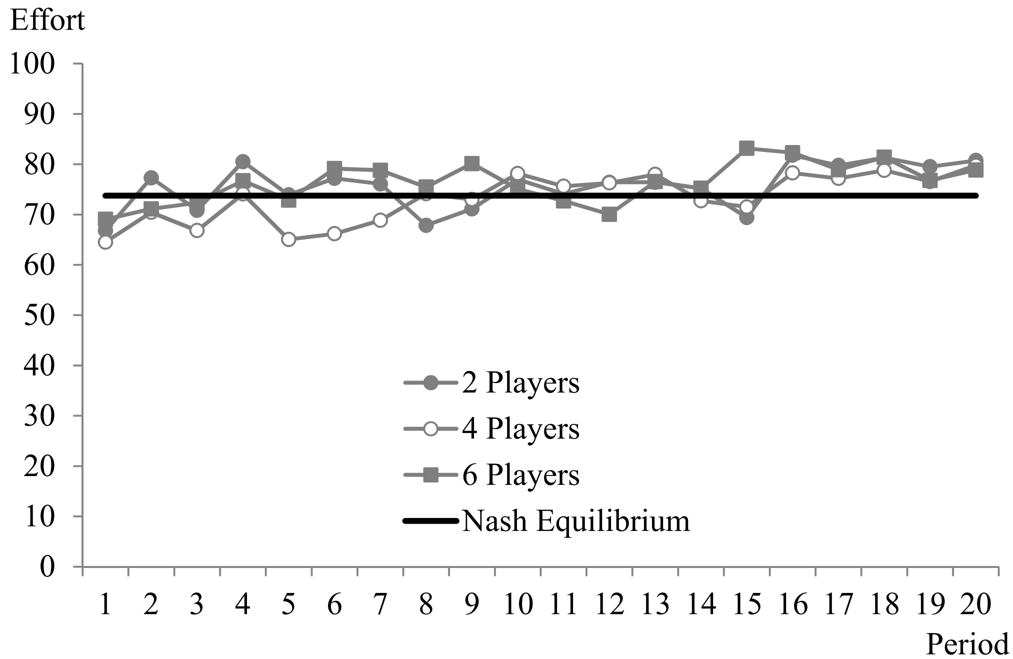
Note: The data are taken from Sheremeta (2010b).

Figure 4: Distribution of Efforts in an All-Pay Auction.



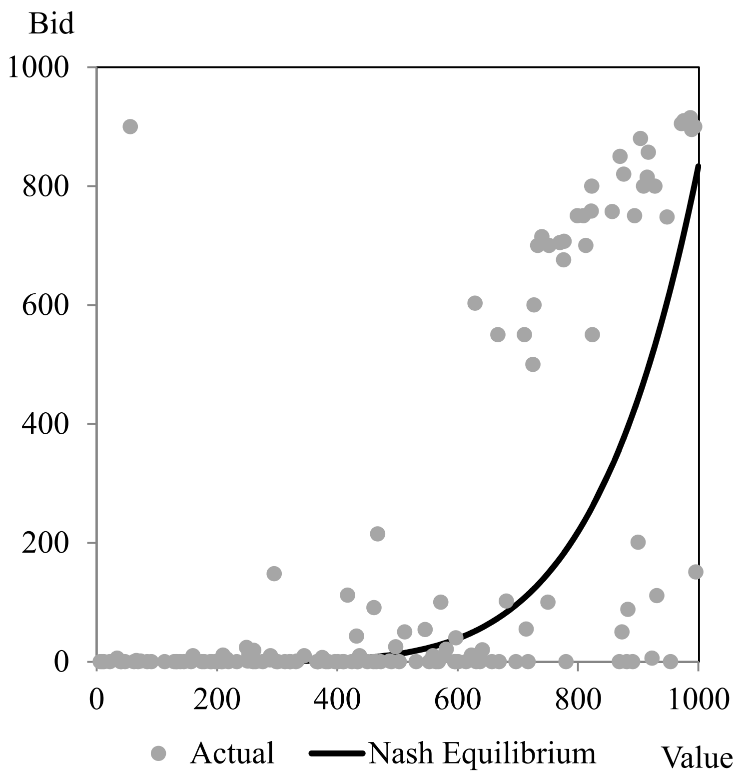
Note: The data are taken from Gneezy and Smorodinsky (2006).

Figure 5: Dynamics of Average Effort in a Rank-Order Tournament.



Note: The data are taken from Orrison et al. (2004).

Figure 6: Bifurcation in the All-Pay Auction with Incomplete Information.



Note: The data are taken from Noussair and Silver (2006).